FINAL REPORT

ESTCP Project RC-200611
Streamlined Archaeo-geophysical
Data Processing and Integration for DoD Field Use

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14. ABSTRACT

This project makes the benefits of an integrated, multi-sensor geophysical approach to characterizing archaeological sites accessible to those who provide cultural resource management support to DoD installations. The project has (1) created *ArchaeoFusion*, a new user-friendly software program; and (2) demonstrated and validated the cost and performance benefits of the approach and technology infusion tool (*ArchaeoFusion*) to DoD geophysical users, representatives of federal, state, and tribal Historic Preservation offices, federal and state resource managers, and other CRM practitioners. The project's demonstration and validation component included a multi-sensor survey of Presidio Los Adaes, a complex archaeological site that includes the subsurface remains of an 18th century Spanish presidio located in west central Louisiana. *ArchaeoFusion*, a user's manual, and a guidance document for new and novice users are distributed at no cost to DoD users by the Center for Advanced Spatial Technologies, University of Arkansas-Fayetteville.

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LIST OF ACRONYMS

2D	Two Dimensional
3D	Three Dimensional
BS	Below Surface
AF	*ArchaeoFusion*
AM	*ArchaeoMapper*
CAST	Center for Advanced Spatial Technologies
CD	Compact Disk
CERL	Construction Engineers Research Laboratory
CESU	Cooperative Ecosystem Studies Unit
CFR	Code of Federal Regulations
COND	Conductivity
CRM	Cultural Resource Management
DoD	Department of Defense
DoT	Department of Transportation
DVD	Digital Video Disk
EDM	Electronic Distance Measurement
EM	Electromagnetic (Induction)
EMI	Electromagnetic Induction
ERDC	Engineer Research and Development Center
ESTCP	Environmental Strategic Technology Certification Program
FCC	Federal Communications Commission
GHz	Giga Hertz
GIS	Geographic Information System
GIS	Geographic Information System
GPS	Global Positioning System
GRAD	Gradiometer
GSSI	Geophysical Survey Systems International
IDIQ	Indefinite Delivery Indefinite Quantity
IMS	Integrated Multisensor Geophysical Approach
MHz	Mega Hertz
MS	Magnetic Susceptibility
NHPA	National Historic Preservation Act
NRHP	National Register of Historic Places
NPS	National Park Service
OH	Overhead
QA/QC	Quality Assurance/Quality Control
RES	Resistance
SAA	Society for American Archaeology
SHA	Society for Historic Archaeology
SHPO	State Historic Preservation Office
SERDP	Strategic Environmental Research and Development Program
SON	Statement of Need
SOW	Statement of Work
STP	Shovel Test Pit

THPO	Tribal Historic Preservation Officer
TDY	Temporary Duty Travel
THPO	Tribal Historic Preservation Officer
UAF	University of Arkansas-Fayetteville
USC	United States Code
USGS	United States Geological Survey
USFS	United States Forest Service
UTM	Universal Transverse Mercator
UWB	Ultra Wide Band

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The project team extends its sincere thanks to the many individuals listed below (and any who were inadvertently omitted) who contributed to the successful outcome of this research.

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ArchaeoFusion Testing and Evaluation

The following archaeogeophysical professionals served as the official *ArchaeoFusion* Army User's group: Laurie, Rush, Fort Drum; Scott Hall, Fort Riley; Steven De Vore, National Park Service, Kent Schneider, U.S. Forest Service (retired). In addition, the following University of Arkansas students participated in the beta test and/or other phases of testing: Jason Herrmann, Stephanie Sullivan, Katie Simon, and Duncan McKinnon. Dozens of other users signed up as "beta testers" and have provided valuable feedback throughout the testing phase. The original assessment of *ArchaeoFusion* was completed by Kent Schneider, Roger Walker (Geoscan Research), and Arne Anderson Stamnes (Arkeolog/Arkeologisk Geofysiker). Fourteen additional users completed the anonymous survey as part of Assessment 2, and many provided valuable comments (see Appendix B).

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EXECUTIVE SUMMARY

A legal requirement and major expense for military installations with active training programs is the evaluation of archaeological sites for the National Register of Historic Places (NRHP). Traditional methods for site evaluation rely primarily on the hand-excavation of shovel tests and small test units, and are invasive, time consuming, costly, and often unreliable. SERDP Project RC-1263 demonstrated that the use and integration of geophysical methods (magnetics, magnetic susceptibility, electrical resistance and conductivity, and ground-penetrating radar) can reduce invasiveness and improve reliability of site evaluations, as well as dramatically reduce the costs of site mitigation (data recovery required when sites are adversely impacted or intentionally removed).Unfortunately, the benefits of the integrated multi-sensor approach were not accessible to DoD Cultural Resource Management (CRM) personnel because of the intense labor and expertise required to process and integrate data from multiple sensors.

ESTCP project "Streamlined Archaeo-Geophysical Data Processing and Integration for DoD Field Use" (Project No. RC-200611) addressed this problem by accomplishing two objectives: (1) Creating *ArchaeoFusion*, a new user-friendly software that allows individuals with relatively modest levels of expertise and experience to accomplish the data processing required by the integrated multi-sensor approach; and (2) Demonstrating and validating the cost and performance benefits of the approach and technology infusion tool (*ArchaeoFusion*) to DoD geophysical users, representatives of federal, state, and tribal Historic Preservation offices, federal and state resource managers, and other CRM practitioners. The project's demonstration and validation component included a number of steps: a) a beta-test of *ArchaeoFusion*; b) a multi-sensor survey of a complex archaeological site, c) processing and integration of the data using *ArchaeoFusion*, d) predictions about the nature of subsurface features, e) an independent evaluation of those predictions by means of small-scale, carefully targeted excavations; and f) dissemination of results through conference presentations and publications.

The field component of the demonstration project was conducted in conjunction with the National Park Service's 2009 introductory course in remote sensing held at Presidio Los Adaes. Located in west-central Louisiana, Los Adaes is a State Historic Site that includes the well-preserved subsurface remains of an 18th century Spanish military outpost. Geophysical data was collected using 5 sensor types that covered areas ranging from .68 to 1.32 hectares. The demonstration surveys revealed anomalies interpreted as various types of archaeological features, including palisades, bastions, a moat, and the walls and floors of internal structures. A number of those interpretations were tested by the excavation of 18 units that exposed an area of 15 m^2. Ground truthing demonstrated that 80% of the features had been correctly interpreted.

An important component of the project was to assess eight performance objectives. Two of these focused on fundamental benefits of the integrated multi-sensor approach: 1) Using multiple sensors provides greater benefits in cost and information return than does using a single sensor, even if data are not integrated. 2) Integrating data from multiple sensors increases the potential for identifying archaeological features. Performance objectives 3 through 7 demonstrated that *ArchaeoFusion*: 3) facilitates data integration; 4) is faster and easier to use than COTS software; 5) allows data from all major sensor types to be downloaded; 6) preserves data resolution; and 7) reduces the time needed for data processing. 8) The final performance objective demonstrated

that ground truthing (verifying interpretations of the data using independent information) increases the usefulness of geophysical data.

Two assessments of the performance objectives were conducted. A minor setback was encountered in Assessment 1 when the project team attempted to secure detailed feedback from volunteers. Providing the information needed to evaluate the eight performance objectives as specified in the demonstration plan required the evaluators to contribute several days of uncompensated labor, which almost none did. ESTCP authorized Assessment 2, which was an evaluation of the performance objectives using anecdotal information that was secured from fourteen evaluators through an online survey. Survey respondents rated their level of agreement or disagreement with 8 different statements, which closely mirrored the performance objectives. The rate of agreement ranged from 46 to 100 percent, with an average of 80 percent. Most cases with lower rates of agreement were due to respondents choosing "neutral" rather than "agree." The results of Assessment 2 strongly support the integrated multi-sensor approach and the use of *ArchaeoFusion* as the technology infusion tool. Specifically, performance objectives1, 2, 3, 6, 7, and 8 were met in Assessment 2. Objective 4 could not be fully assessed due to insufficient data. Objective 5 had split (positive and negative) results.

The cost and performance model included costs associated with purchase of *ArchaeoFusion* (free to DoD users); supplemental graphic software ($700); up to five sensors ($20,000 to $100,000); and labor and travel associated with training and geophysical survey ($9,428 for the first sensor, less for additional sensors). The adjusted cost of the geophysical survey and ground truthing done at the demonstration site was $61,359. An NRHP evaluation of Los Adaes could have been done for approximately 25% of the adjusted costs ($15,339) documented in this study. That percentage could be greater, of course, for sites where it was more difficult to differentiate features from non-feature anomalies in the geophysical data. Conducting the same project using a traditional approach would require at least twice as much excavation (since many units would fail to encounter informative features), bringing its cost to $88,808.

A large-scale mitigation of the demonstration site using the traditional approach to excavate 63 m^2 would cost $186,496. That amount would be sufficient to purchase 3 sensors, train one user, survey 5.47 ha, and excavate 29 m^2. That area is a little less than 50% of the area excavated by the traditional approach, but would likely be adequate because all of the units would be targeted on promising anomalies. When a second, very similar site was mitigated using the integrated multi-sensor approach, the costs of purchasing the sensors and training an operator ($82,844) would already have been met. The second mitigation could therefore be done for $103,652. On balance, we suggest that adopting the integrated multi-sensor approach could reduce the costs of NRHP evaluation and mitigation of relatively large, complex sites by roughly 50 to 75%.

It is recommended that installations considering adoption of this strategy should first ensure that they have a considerable number of relatively large and complex sites that are amenable to geophysical survey, likely to include discrete features, whose NRHP-status needs to be evaluated, and/or that represent serious obstacles to the mission and therefore need to be properly removed (mitigated). Future reductions in funds available to manage cultural resources on DoD installations may make it more cost effective for installations to require private sector firms who conduct their site evaluations to employ the integrated multi-sensor approach. This would transfer start-up costs to the private firms but would still allow DoD to realize the cost and performance benefits that accompany use of the integrated multi-sensor approach.

1.0 INTRODUCTION

Archaeologists in the US have been very slow to integrate geophysics (including ground penetrating radar, magnetometry, magnetic susceptibility, electrical resistance and conductivity) into Cultural Resource Management (CRM) and other research. Early efforts to demonstrate how the approach could contribute to archaeology were largely successful (Bevan 1991; Bevan and Kenyon 1975; Carr 1982; Dalan 1991; Kenyon 1977; Weymouth and Nickel 1977; Weymouth and Woods 1984), but many archaeologists seem to have concluded that geophysics was too complicated, expensive and/or unreliable. Archaeological deposits at prehistoric sites in North America exhibit relatively low geophysical contrast with their surroundings and represented challenging targets for early surveys. CRM in the US was—and to some extent, still is—methodologically conservative. CRM firms competed for funding that was very modest in comparison to other disciplines that use geophysics. US archaeologists have traditionally been trained as social scientists, and often had little first-hand exposure to “high-tech” developments in the sciences. Field archaeology has long been based on meticulous hand-excavation and many archaeologists assumed that only that approach (perhaps combined with mechanized removal of the disturbed plow zone) could reveal the nature of subsurface deposits.

The acceptance of geophysics lagged behind other technologies such as geographic information systems (GIS), electronic distance measurement devices (EMD), and global positioning systems (GPS). Costs associated with those systems were initially perceived as high, but the ratio of cost to capabilities improved markedly, and benefits to CRM users (efficient mapping, new capabilities for spatial analysis and predictive models) were readily apparent. Geophysics has still not achieved a comparable level of acceptance, but may now be poised to do so. Sensors are more user-friendly; cart-mounted sensors, light-weight dual systems, and advances in computer technology have dramatically reduced the cost of data acquisition. Limitations in data processing software and the continued lack of a sophisticated understanding of how geophysics should be integrated into archaeological research continue to be limiting factors.

Since 1990, the National Park Service’s annual introductory course in remote sensing (and similar classes) has demonstrated the benefits of geophysics to prospective users and sponsors. Academic centers of expertise have emerged. The Center for Advanced Spatial Technologies (CAST) was established at the University of Arkansas-Fayetteville in 1991 and its efforts to integrate GIS, GPS, photogrammetry, laser scanning, and related technologies (archaeo-geophysics was added in 2000) have included many archaeological applications (CAST 2012). Other universities with established geophysical expertise include Mississippi, Notre Dame, Indiana, and Indiana-Purdue at Fort Wayne. Numerous other universities have acquired sensors and are developing capabilities. A growing number of case studies have been published, and many more presented at professional conferences over the past decade by academic, CRM, agency, and specialized archaeo-geophysical researchers (Butler et al. 2011; Johnson 2006; Kvamme 2001, 2003, 2008; Kvamme et al 2006).

The Engineer Research and Development Center (ERDC), Construction Engineering Research Laboratory (CERL) adopted archaeo-geophysics as an area of applied research in the late 1990s. A Controlled Archaeological Test Site (CATS) was constructed at CERL in Champaign Illinois, (Isaacson et al. 1999); geophysical surveys were integrated into National Register of Historic

Places (NRHP) evaluations of archaeological sites at Fort Riley (KS), Poinsett Air Combat Range (SC), Fort Leonard Wood (MO), and Fort Benning (NC); and guidance documents were developed for DoD and other users (Hargrave 1999a, 1999b; Hargrave et al. 2002; Zeidler 1997; Somers and Hargrave 2003). ERDC partnered with UA-F and CAST in SERDP-sponsored research (described below) led by Kvamme and Limp (Kvamme et al. 2006), and continues that institutional relationship with the ESTCP demonstration and validation project reported here.

1.1 BACKGROUND

A major component of the Cultural Resources Management (CRM) work conducted on military installations is the evaluation of prehistoric and historic archaeological sites for National Register of Historic Places (NRHP) eligibility in compliance with federal laws. Traditional methods for site evaluation based on hand excavation are costly, invasive, time consuming, and potentially unreliable. A SERDP project completed in 2006 [RC-1263, *New Approaches to the Use and Integration of Multi-Sensor Remote Sensing for Historic Resource Identification and Evaluation* (Kvamme, et al. 2006)] developed methods that provide exceptionally detailed, remotely sensed images of the subsurface, permitting accurate characterization of archaeological deposits for a wide range of sites. That research not only demonstrated that remote sensing (including satellite, aerial, and ground-based geophysical sensors) can produce a level of information about subsurface deposits far richer than that provided by highly invasive traditional approaches, but also that relatively large area (1-2 ha) field surveys using multiple instruments can be cost effective. However, the inordinate amount of time required to manually process and integrate (combine into one) data produced by each instrument is a primary obstacle to much broader adoption and effective use of the integrated multi-sensor approach. The SERDP research found that fully processing and fusing data from a multi-sensor survey typically requires the expert-level use of seven or more commercial-off-the-shelf (COTS) software packages and hundreds of hours of repetitive work. Making remotely sensed information readily available to DoD CRM programs by streamlining data processing and integration will dramatically reduce labor costs and expertise requirements, and will enhance the information content and reliability of survey results (i.e., interpretations of images revealing subsurface cultural deposits).

This ESTCP project has sought to demonstrate and validate the integrated multi-sensor geophysical approach to archaeological site characterization. This project has developed *ArchaeoFusion*, a new, user friendly software that will make the cost and performance benefits of this approach accessible to a wide range of non-expert users. In this document, the "technology" refers to both the integrated multi-sensor geophysical approach and the *ArchaeoFusion* software that is the method's technology infusion medium.

1.2 OBJECTIVE OF THE DEMONSTRATION

This ESTCP project has two fundamental objectives: The first is to assemble a single, user-friendly software that will serve as an effective medium for infusing the integrated, multi-sensor geophysical approach into wide use. The second objective is to demonstrate and validate the cost and performance benefits of the approach and technology infusion tool to DoD geophysical

users, representatives of federal, state, and tribal Historic Preservation offices, and other CRM practitioners, federal and state resource managers.

Demonstration of the technology has been divided into two phases: 1) demonstrate that the *ArchaeoFusion* software (the technology's infusion tool) is capable of performing all the tasks required to process, integrate, and interpret geophysical data. 2) Demonstrate all the aspects of a multi-sensor geophysical site evaluation, including instrument set-up and preparation; field data collection, data processing and integration using *ArchaeoFusion*; and interpretation of the data in terms of archaeological features and other deposits and the benefits in improved decision making and cost reduction to DoD programs. *ArchaeoFusion's* capabilities to perform all aspects of data processing and fusion were demonstrated during a beta-test of the software conducted in November 2008; a report on the beta test was submitted to ESTCP on 15 January 2009. The second phase of the demonstration continued through September 2011 and was described in a demonstration plan submitted to ESTCP on May 15, 2009. All aspects of the second phase of the demonstration were accomplished in conjuction with the National Park Service's 2009 introductory course in remote sensing, held at Los Adaes State Historic Park in Louisiana. The work at Los Adaes was a major component of this project with exciting outcomes that effectively demonstrated all aspects of the multi-sensor geophysical approach to archaeological site evaluation.

A User Group comprised of DoD (Army) and civilian agency (e.g., NPS, USFS) personnel who currently use remote sensing in their CRM programs participated in the beta test with the ESTCP project team, and also participated in the project's field demonstration phase at Los Adaes State Historic Park. Members of the User Group are intermediate to highly experienced remote sensing users with strong backgrounds in archaeology. Other participants in the demonstration included representatives of agencies that could play a role in the broader use of the technology, and the students and instructors of the 2009 National Park Service (NPS) introductory class in remote sensing.

1.3 REGULATORY DRIVERS

The National Historic Preservation Act of 1966, as amended, and it's implementing regulations (36 CFR 800) requires federal agencies to take into account the effects of their undertakings on historic properties (including archaeological sites) that are or may be eligible for the National Register of Historic Places (NRHP). Evaluating a site's NRHP eligibility status often requires archaeological excavations designed to evaluate the site's integrity (the condition of its deposits) and significance relative to established criteria. Sites that are or (in the case of unevaluated sites) may be eligible for the National Register must be protected; adverse impacts that cannot be avoided must be mitigated. Section 106 of the NHPA outlines a process for implementing this requirement, and compliance with this process is one of the primary responsibilities of agency CRM personnel. Each state has an office that functions as the State Historic Preservation Office (SHPO), implementing compliance with NHPA and other historic preservation laws. Most states have developed a body of standard professional practice concerning requirements or guidelines for field investigations, reporting, etc. Many federally recognized Indian Tribes maintain their own Tribal Historic Preservation Offices (THPO).

NAGPRA, the Native American Graves Protection and Repatriation Act (Public Law 101-601; 25 U.S.C. 3001-3013) specifies that planned excavations that may result in the discovery of human remains must be conducted under permit and only after consultation with appropriate Native American groups. Native American groups have certain oversight prerogatives concerning undertakings on federal lands that may be covered by NAGPRA, and in situations where potential adverse impacts are likely, many Native American groups advocate non-invasive or minimally invasive approaches to site evaluation. Federal and State agencies and, in some cases, municipal areas typically have qualified personnel to ensure compliance with relevant historic preservation laws and regulations in a manner consistent with their own missions. The mission of many US military installations is to house and train military personnel. Realistic military training requires use of very large tracts of land. Archaeological sites are numerous and widely distributed across the landscape, and the need to avoid or mitigate adverse impacts to sites is a major cost factor, as well as a logistical obstacle to military training.

2.0 TECHNOLOGY/METHODOLOGY DESCRIPTION

The following describes the technology and methodology used in this project, including the integrated multi-sensor geophysical approach and *ArchaeoFusion* as the technology infusion tool.

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

The following subsections describe the methodology, its development, and expected applications.

2.1.1 DESCRIPTION OF THE METHODOLOGY

The integrated multi-sensor geophysical approach is based on the finding (Kvamme, et al. 2006) that data from a suite of sensors (ground-penetrating radar, magnetometry, electrical resistance, induced electrical conductivity, magnetic susceptibility, multispectral scanning, panchromatic photography, and thermography), when properly processed and integrated, yield images of subsurface deposits that are of considerable value to cultural resource managers (Figure 2-1). In particular, use of these methods can enhance the reliability and reduce the invasiveness of investigations needed to characterize the nature and condition of an archaeological site's subsurface deposits, and to evaluate the site's NRHP eligibility status. The use of multi-instrument data integration ("fusion") algorithms for archaeological remote sensing was pioneered in SERDP project RC-1263, including the successful implementation of color compositing, principle components analysis, logistic regression, decision tree, image segmentation and related image classification (Kvamme, et al. 2006). In order to integrate these data from different sensors, however, a number of initial processing steps are required. "Raw" (unprocessed) remote sensing data are not reliably interpretable in terms of the presence/absence and nature of cultural deposits (Figure 2-2). A relatively complex sequence of data processing steps is required to produce an optimal (or even usable) image (Clark 1996), and then to integrate these images together with other results (Figure 2-3). Data processing includes numerous preprocessing routines necessary to make raw data suitable for integration, display, and interpretation. Very few CRM practitioners have the expertise required to implement the multi-sensor integrated approach. This ESTCP project has developed *ArchaeoFusion*, a new, user-friendly software tool that allows a wide range of users to implement the approach and achieve its benefits in terms of increased reliability, reduced invasiveness and costs. In short, *ArchaeoFusion* serves as the technology's infusion tool. Figure 2-4 shows how the steps in Figure 2-3 can be reduced by using *ArchaeoFusion*.

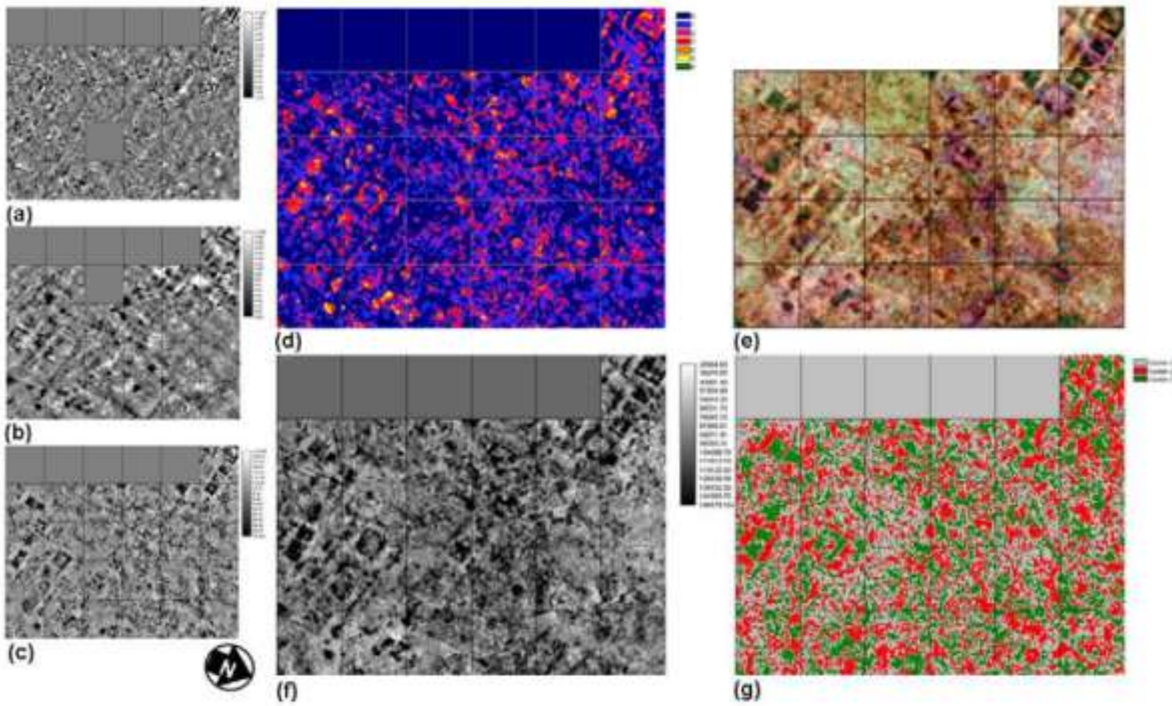


Figure 2-1. Selected Geophysical Data Layers and Integration outcomes exemplified with RC-1263's Pueblo Escondido (a) magnetic gradiometry, (b) magnetic susceptibility, (c) one of four ground-penetrating radar slices, (d) integration of results by adding together binary representations of significant anomalies from each data layer, (e) color translucency overlay of ground-penetrating radar (tinted red), soil conductivity (green), and magnetic susceptibility (blue), (f) mathematical product of all layers, and (g) 3-cluster solution of unsupervised classification of all data layers.

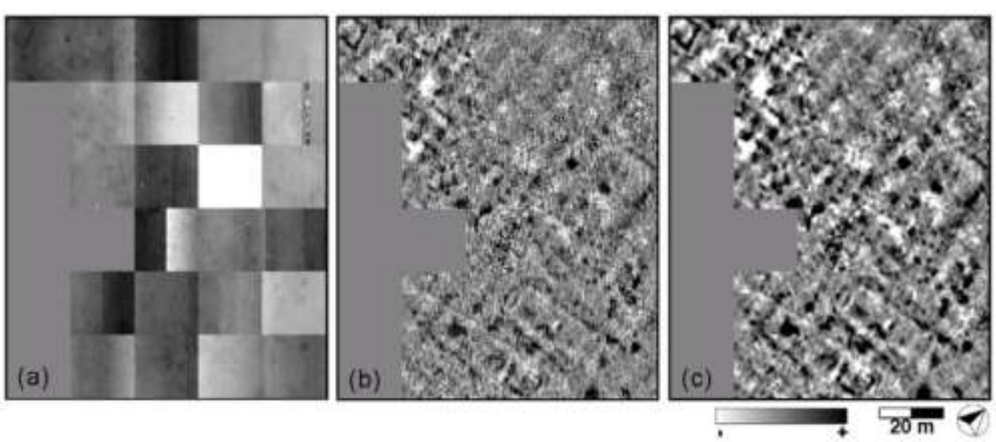


Figure 2-2. Processing sequence for Pueblo Escondido magnetic susceptibility acquired and processed for SERDP project RC-1263: (a) unprocessed, (b) basic processing applied, and (c) image enhancement.

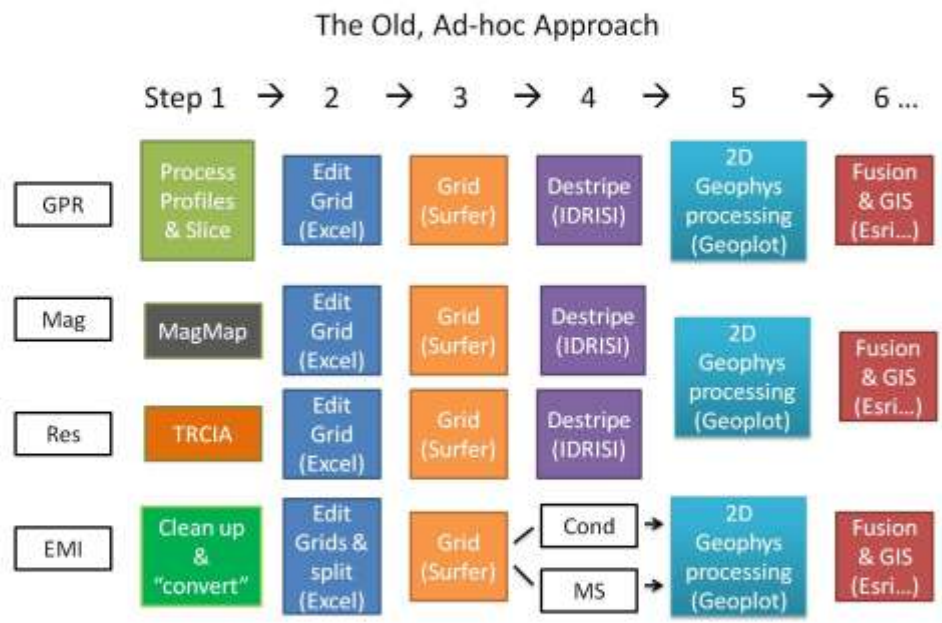


Figure 2-3. Flowchart illustrating the old, ad-hoc approach of processing and integrating multiple geophysical datasets. Each color represents a different software package or type of software. White represents original datasets.

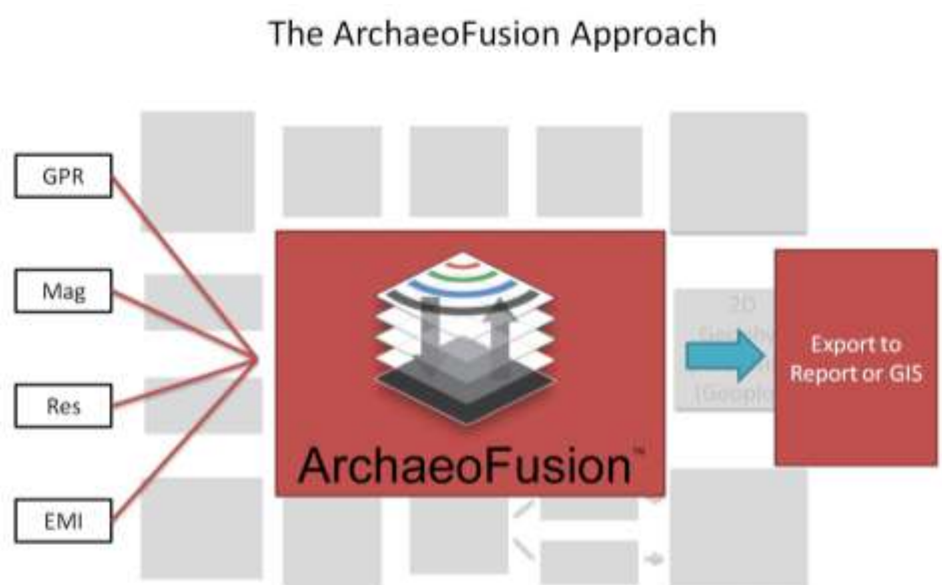


Figure 2-4. Using *ArchaeoFusion* streamlines data processing and integration by keeping the data in the same software environments from beginning to end. Final products can be exported as images for publishing in reports, presentation, and on the web, or for integration with other types of data such as line drawings in GIS or similar software.

ArchaeoFusion provides for a full range of data processing and integration options for the expert user as well as pre-loaded macros designed to guide novice and intermediate practitioners through the processing steps. Substantial benefit in particular has been realized in streamlining ground penetrating radar (GPR) processing, but cost savings have been realized for the processing, integration, and fusion of data collected from all supported sensors. *ArchaeoFusion* maintains all data in a single software environment while preserving spectral resolutions and recording processing steps for metadata documentation (the old ad-hoc approach inherently entails the loss of spectral resolution and inhibits the ability to keep track of each transformation as data are moved from one software environment to the next for manipulation).

Data integration entails the use of various graphical, mathematical, and statistical algorithms to combine multiple images (processed data sets) into one image that portrays the pertinent information from each layer (data from a single sensor). A number of sensor types (listed above) are useful in remote sensing investigations of archaeological sites because the various sensors respond to different physical properties of the archaeological record. It is frequently difficult to predict which single sensor will provide the best results at a particular site. Optimization of a remote sensing investigation typically requires use of *at least* several different instruments and processing tools.

The expertise needed to bring GPR data processing up to the same level of efficiency as other archaeo-geophysical methods now exists, but (prior to *ArchaeoFusion*) had not yet been implemented in software. On balance, multi-sensor surveys can currently only be competently undertaken by a limited number of specialists that have mastered a large number of highly disparate software and data processing protocols. Labor undertaken by such specialists is understandably expensive, yet their work requires hundreds of hours of repetitive processing and data management. Transformations of data from one software package to another present numerous opportunities for error, and the fact that many of the current systems require conversion of data to alternative formats means that important spectral information can be needlessly lost. By remedying this situation, *ArchaeoFusion* substantially reduces the high cost of archaeological remote sensing.

ArchaeoFusion is designed as a platform to integrate, as much as possible, the various processes required in a multi-sensor survey approach. The graphical user interface is written in Java 1.5 using the Swing, Java OpenGL and Java Advanced Imaging Library components. All processing operations are coded in Matlab 7.1 and its Image Processing, Signal Processing and Curve Fitting Toolboxes. Several open-source libraries exist for processing Geophysics data and were examined as possible inclusion into *ArchaeoFusion*. However, most of these libraries are poorly documented, have limited functionality and were designed as stand-alone executables. The difficulty of integrating these into our code-base was deemed to be more expensive than replicating the functionality in a consistent way. As a result, all of our operations are developed in Matlab in a consistent, well documented form. One exception to this general observation is a code-base developed by USGS researchers Lucius and Powers (GPR Data Processing Software for the PC, http://pubs.usgs.gov/of/2002/ofr-02-0166/ofr02_166.pdf). This code base was published in 2002, is well-documented and efficient but supports only Windows 2000 operation system on 32-bit processors. Since *ArchaeoFusion* is designed to operate on both 32-bit and 64-bit processors (to take advantage of the additional memory for GPR processing in particular) in Windows XP and VISTA, we decided to implement the necessary functionality in Matlab and

Java. The Matlab libraries available in the Image and Signal Processing toolboxes are extensive and, as expected, provided a strong foundation to develop the operation functionality.

Within *ArchaeoFusion*, all work is organized into various projects. Projects are stored as combination ASCII and binary files comprising data collected from various instruments at one or more sites and all the operations used to process this data. The interface to the project file (i.e., *ArchaeoFusion* itself) consists of two primary components. The *Survey Tool* (Figure 2-5) is used to load data in multiple formats, arrange the "tiles" of data (e.g., the data collected in one of a series of small blocks of various sizes and shapes) into a single "survey" and provide access to utilities designed to correct geometric (or data placement) errors associated with sample rates and instrument malfunction. The survey itself is positioned and oriented within a global reference frame using external data input by the user. The relationship between tiles, surveys and projects is shown in Figure 2-6. Once assembled and assigned global coordinates, the survey is added to the project and loaded into the *Main Window* (Figure 2-7) as a new layer. This interface provides access to general and data specific processing tools that can be assembled into an "operation stack", in which a series of sequential operations are defined and run in a single step. Each survey will have a unique chain constructed by the user.

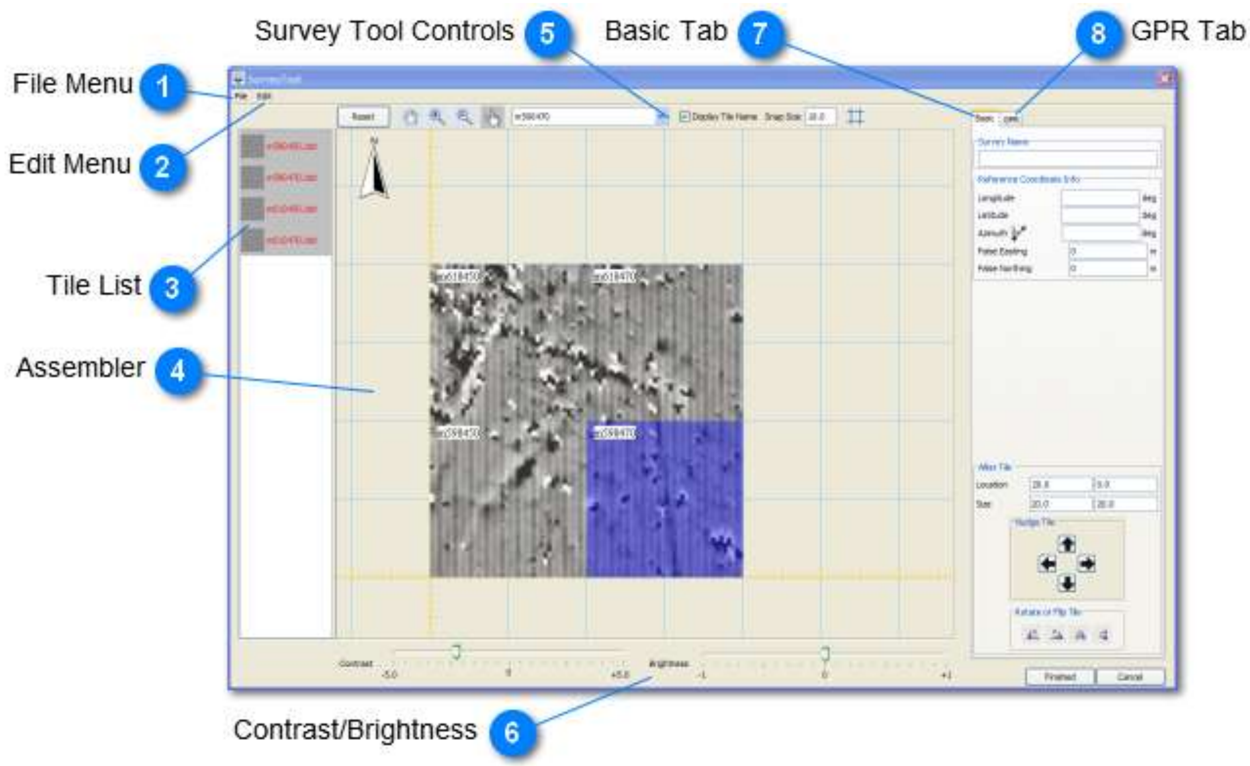


Figure 2-5. The Survey Tool contains all tools needed to import and assembled individual data tiles into site-wide surveys.

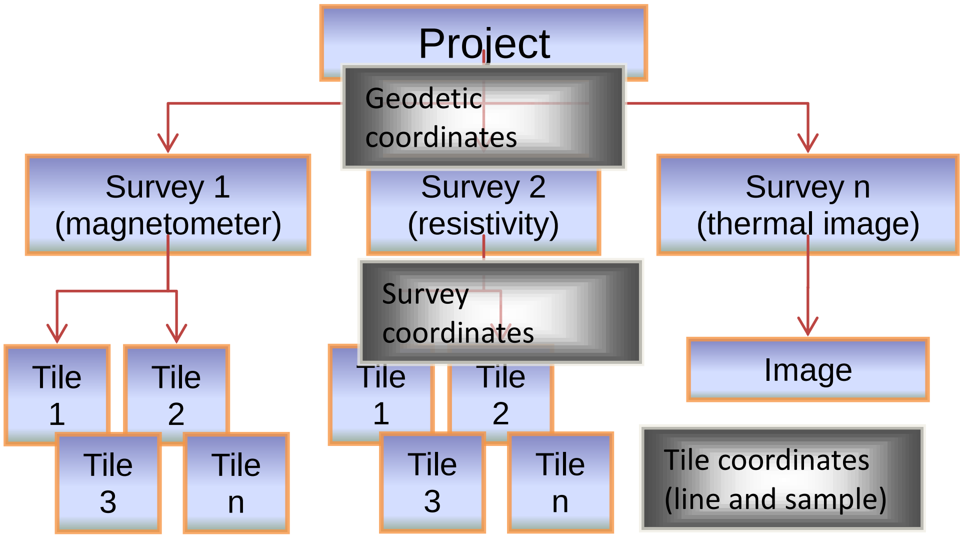


Figure 2-6. Project structure showing how raw data tiles are organized into surveys and surveys into projects.

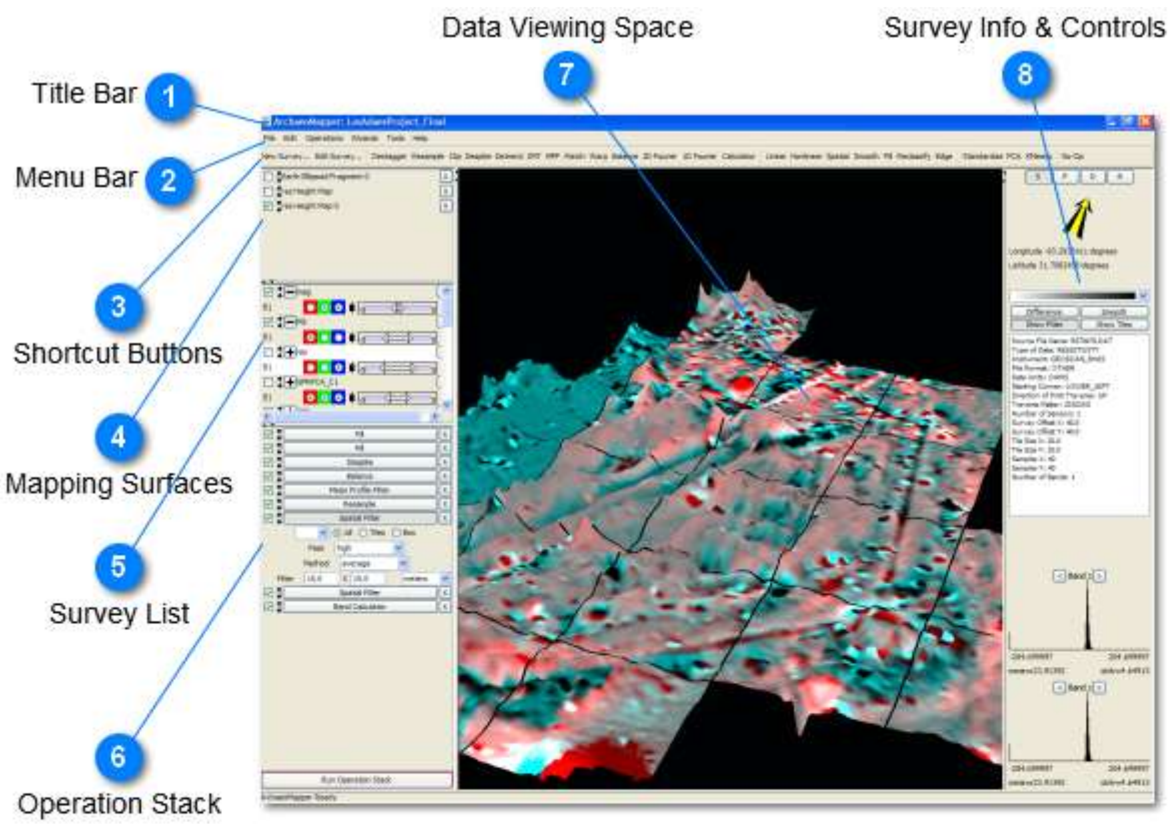


Figure 2-7. Main *ArchaeoFusion* Viewing Window and processing environment.

Novice users will take advantage of pre-loaded macros, which are saved operation stacks that are designed to yield acceptable results in most circumstances. If the user is not satisfied with the results, any parameter within the chain may be modified to see its effect on the final processed image. If GPR data are included in the project, the GPR Loader (Figure 2-8) facilitates each step of data processing, beginning with loading individual reflection profiles and including filtering, gaining, calculating velocity, and slicing. A 3D cube is created and then sliced, creating a multi-band image for processing with other 2D data. The data cubes can be re-sliced using different algorithms and thicknesses at any time.

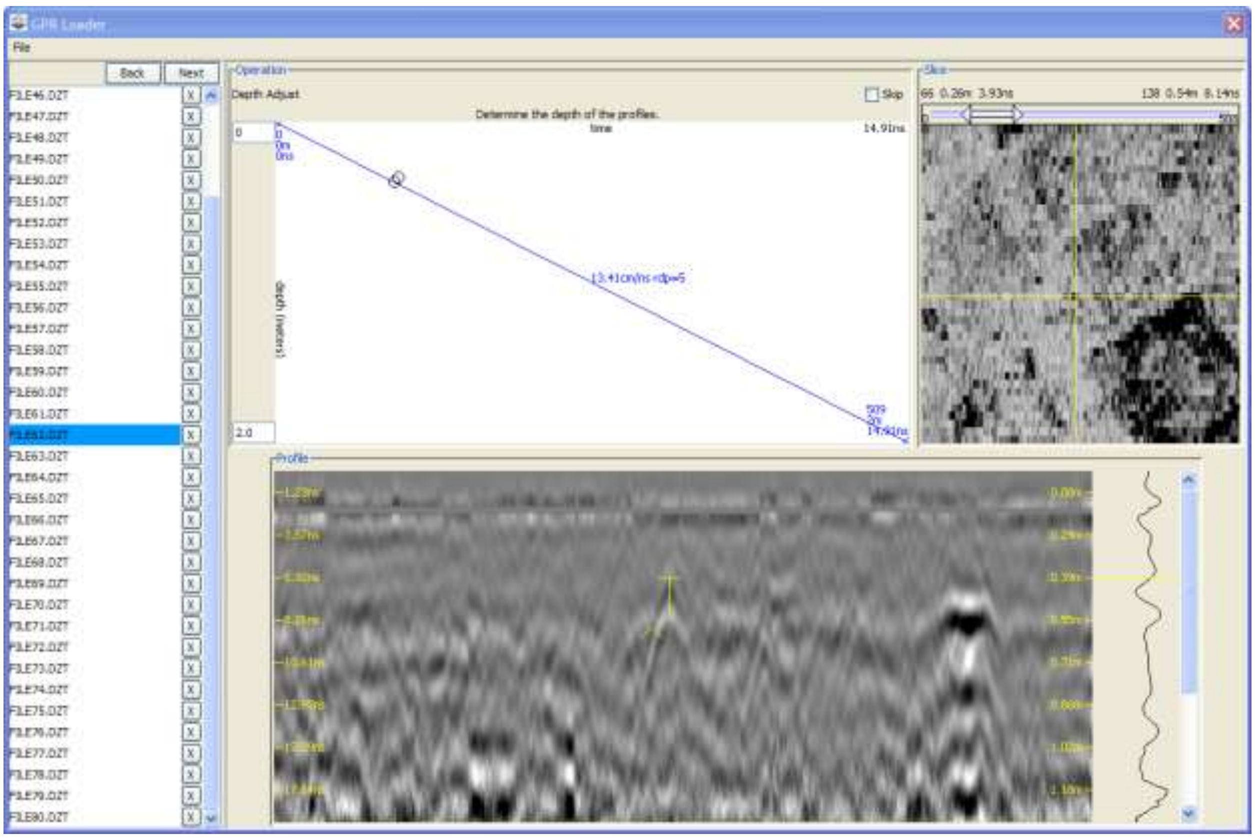


Figure 2-8. The GPR Loader, where users are guided through the steps for processing GPR data and creating 2D slice images.

As multiple layers (or surveys) are added to the layer stack, fusing operations become active. The operations range from simple interactive color composite and translucent display, to “band-math” operations (e.g. add 10% of layer 1 to 90% of layer 3 and display the logarithm base 2 of the result), to sophisticated statistical operations such as principal component analysis. The viewing environment is natively 3D, so that layers may be viewed from a variety of view-points and overlaid on digital elevation data available from any source.

2.1.2 Chronology of the Methodology's Development

Remote sensing (a term widely, if imprecisely, used synonymously with 'geophysical') techniques have been used in archaeological investigations for many years. Aerial photography came into use by archaeologists shortly after the First World War. Two techniques that have proven to be of great value for archaeology—electrical resistance and magnetometry—were pioneered in the UK. Electrical resistance was first used at an archaeological site in 1946 by Richard Atkinson (Atkinson 1953; Clark 2001; Gaffney and Gater 2003:14), and Martin Aitken used a proton magnetometer to detect kiln and earth-filled pits in the UK as early as 1958 (Atkinson 1953; Clark 1996; Gaffney and Gater 2003). The early adoption of geophysics by British archaeologists was largely a result of the common occurrence of high contrast materials (e.g., metal artifacts, fired clay roofing tiles, brick and stone building materials) at prehistoric, Roman, medieval, and later sites. Useful maps of such sites could be made by the earliest sensors long before the advent of digital data recorders and computer-based graphics. In one of the earliest (1938) applications of geophysics to archaeology in the US, equipotential (a technique that is rarely used in archaeology) was used search for a stone vault suspected to be associated with an early church at Williamsburg, VA. Despite important pioneering work in the US by John Weymouth, Bruce Bevan, and others, geophysical techniques were not widely used in the US until advances in information technology made it possible to record and map the relatively high density data needed to detect very low contrast feature types like earth-filled pits. There are now at least some archaeo-geophysical practitioners in most states, and articles documenting successful surveys have appeared in a number of professional journals and at many conferences. Despite this progress, most established archaeologists in the US have not used geophysics, State Historic Preservation Offices (SHPO) typically do not yet recognize geophysical techniques as viable alternative to traditional excavation, and geophysics is not well integrated into CRM. The 1980s and 90s saw a gradual increase in the use of geophysics in the US, accompanied by parallel advances in the use of Geographic Information Systems (GIS), Global Positioning Systems (GPS), and electronic distance measurement (EDM, or "total station") instruments. GIS, GPS, and EDM technologies are now thoroughly integrated into CRM in the US, and a younger generation of CRM professionals is far more open than their predecessors to the incorporation of geophysics into their management and research programs.

SERDP project RC-1263, led by Ken Kvamme and Fred Limp, demonstrated that the potential benefits of an approach based on the integration of data from a suite of geophysical sensors included increased information return and reliability and decreased invasiveness and (in many cases) cost (Kvamme, et al. 2006). The present ESTCP project has demonstrated the feasibility and benefits of an integrated multi-sensor approach to a much broader audience, particularly CRM personnel of federal, state, and tribal agencies. *ArchaeoFusion* has been developed to serve as the technology's infusion tool, making the approach's benefits available to a wide group of CRM professionals who do not have extensive experience and expertise in geophysical techniques. *ArchaeoFusion* was beta-tested in November 2008. Outcomes from this test led to a number of code corrections and design modifications. Project participants and a small group of additional users have continued to use *ArchaeoFusion* and provide regular comments which allow the development team to continually improve the functionality and robustness of the software. *ArchaeoFusion* will soon be made available to the public and funds from public sale will be used to maintain the software and improve functionality as needed.

The *ArchaeoFusion* software is delivered via a dedicated website (www.archaeofusion.org shown in Figure 2-9). From this website a user may download updates (the software checks for updates at startup and can download and install updates automatically), the user's manual (Figure 2-10), and sample data. A user's forum is also provided and linked from this website. The forum is a venue for user questions and information from the development team. The project team has engaged the University Technology Licensing Office to assist in the commercialization of the *ArchaeoFusion* and is currently working to develop a business model that allows a University of Arkansas Unit - likely the Center for Advanced Spatial Technologies (CAST) – to distribute and maintain the software using proceeds from the sale of the software application via a CAST or CAST affiliated website. The mechanism for funds transfer is not yet in place but is expected by the first quarter of 2012.

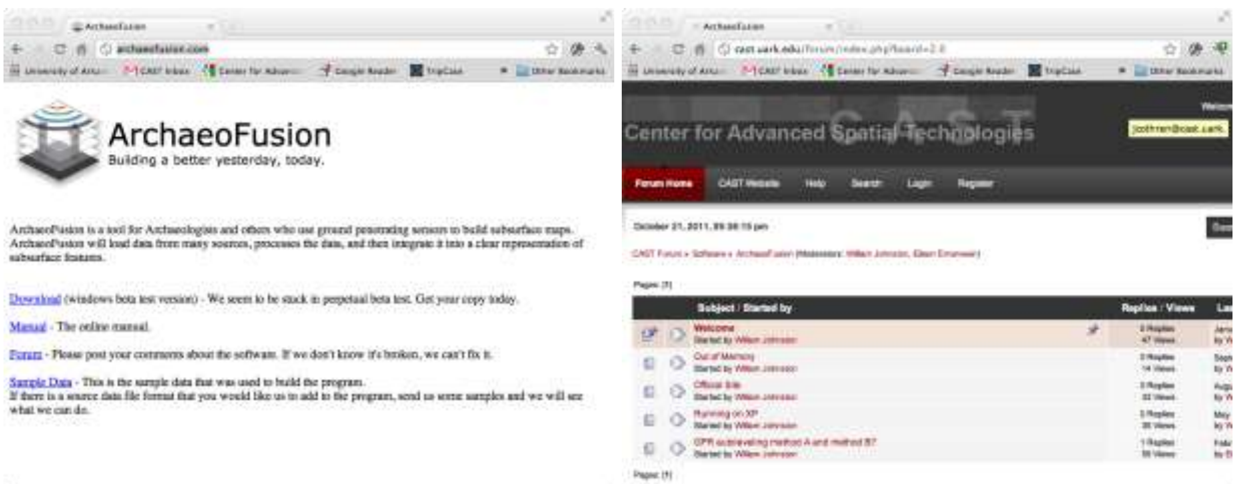


Figure 2-9. *ArchaeoFusion* website (left) and the User's forum (right).

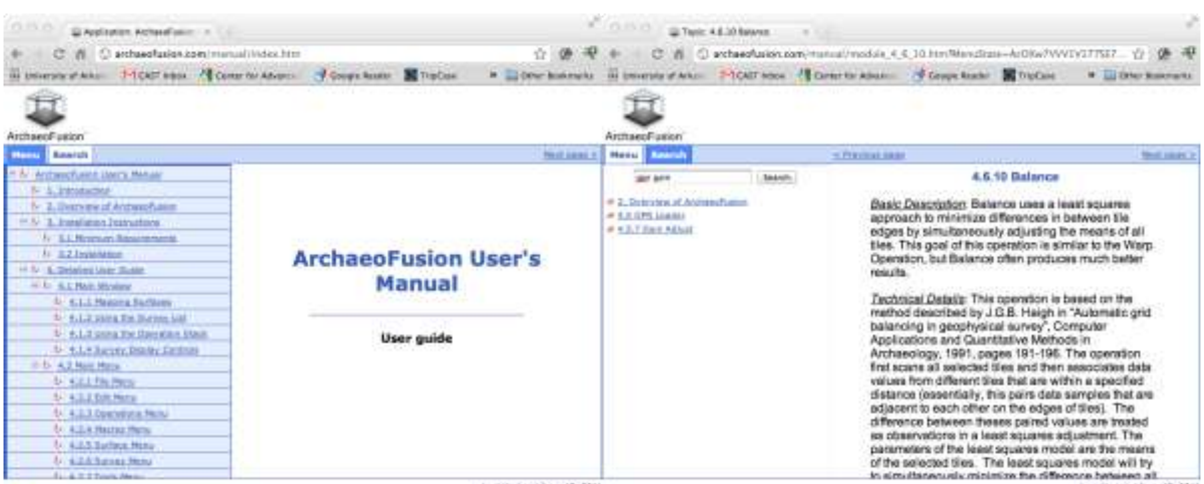


Figure 2-10. Online *ArchaeoFusion* user's manual accessible from the *ArchaeoFusion* website. The entry page is shown on the left while the search function is shown on the right.

2.1.3 Expected Applications of the Technology

Archaeological investigations executed in compliance with Section 106 of the NHPA are generally divided into three phases: 1) field surveys (and archival searches) undertaken to discover sites; 2) NRHP eligibility evaluations (generally based on test excavations); and 3) mitigation of unavoidable adverse impacts to NRHP-eligible sites. Geophysics is rarely included in the first phase simply because most of the techniques are slower and more expensive than traditional, broadly accepted methods like surface inspection of plowed fields and systematic shovel testing (aerial and satellite based sensors can detect some but not most sites – particularly in North America). Reliability of the traditional field methods is heavily dependent on sampling designs (e.g., number of shovel tests per hectare), but CRM practitioners have long accepted the risks (e.g., not finding small sites and potentially important subsurface features) that accompany their use.

Geophysical survey can be very useful in NRHP evaluations, particularly if the site in question is large and/or complex, or if special circumstances (such as the possible presence of Native American burials) argue against excavation. It is in the area of planning for site mitigation where the benefits of geophysical survey can be the greatest. Mitigation of damage to archaeological sites typically includes large scale hand excavation, analysis of the artifacts recovered, publication of results, and long-term curation of artifacts and records. Effective use of geophysics can target excavation units on important or representative areas, reducing the overall amount of excavation needed, as well as costs associated with analysis and curation. DoD does not presently undertake much mitigation of archaeological sites, primarily because mitigation is so expensive. Reductions in the cost of site mitigations will make it far more feasible to "remove" sites whose avoidance represents a real impediment to realistic military training.

Geophysical services can currently be acquired by DoD CRM programs in several ways. A number of small consulting firms focus primarily on geophysical investigations. Using such consultants is less expensive than purchasing equipment in situations where geophysics will be infrequently used. The highly specialized "itinerant" geophysical consultant can be cost effective, but the difficulty of ensuring his or her input into ground truthing investigations that often occur long after the geophysical work is completed can diminish the reliability of data interpretations. A small number of the larger CRM consulting firms have geophysical capabilities. This option can be particularly effective when a DoD installation can hire the same firm to do ground truthing excavations. The third option is for a DoD CRM program to develop its own in-house geophysical capability. This requires the purchase of equipment (sensors typically cost between $15,000 and $25,000, and the need for at least one member of the CRM team to have the expertise needed to collect, process, and interpret geophysical data. An in-house geophysical capability is clearly the preferred option for CRM programs that manage a large number of sites, since it results in the greatest degree of flexibility and autonomy. Although the start-up costs (of instrument purchase) are substantial, in the long run it may be desirable for the installation's CRM team to amortize their own equipment rather than subsidizing equipment purchased by a consulting firm (Ernenwein and Hargrave 2007; Hargrave 2007).

2.2 TECHNOLOGY/METHODOLOGY DEVELOPMENT

2.2.1. *ARCHAEOFUSION* VERSIONS 0.1 – 0.5 (OCTOBER 2006 – NOVEMBER 2008)

Regular design and review meetings were held to develop the initial capability requirements, design the system architecture, and design the user interface. Participants included Drs. Fred Limp, Eileen Ernenwein, Bill Johnston, and Jackson Cothren. Review meetings were held approximately every month to discuss progress and suggest modifications. The development team decided that a spiral design progress was the best approach to the project. A considerable amount of attention was given to the software architecture. Java 6 was chosen as primary development environment because of Dr. Johnson's familiarity with the language and because of the relative ease with which it could be integrated with Matlab. Matlab R2007b was chosen as the primary analytical engine, with an understanding that as Mathworks, Inc. released new versions the software would also be updated to the latest version. Although Version R2007b was tightly integrated with Java 6, the latest versions - Java 7 and Matlab R2011b are even more tightly coupled. The tighter coupling would have simplified the code significantly. Unfortunately, design decisions made using earlier versions created code that was too imbedded in the software to be easily modified to take advantage of the new language versions. At some point in the future, the development team expects to make this modification in an *ArchaeoFusion* Version 2 release.

2.2.2. *ARCHAEOFUSION* VERSIONS 0.6 – 0.9 (NOVEMBER 2008 – MARCH 2009)

An extensive guided beta-test was conducted at the University of Arkansas on November 6-10, 2008 (details were provided in the Beta Test Report). Tables 2-1 and 2-2 list problems and shortcomings identified by the beta test participants paired with changes made by the *ArchaeoFusion* development team to resolve the issues. Table 2-3 is a list of comments and suggestions for the GPR component of *ArchaeoFusion*, but resolutions are not listed because this aspect of the software was completely redesigned in March 2009, making the specific comments irrelevant. These comments, however, were important considerations in the design of the new GPR component, discussed in the next section.

Table 2-1. Beta Test Comments and Resolutions: User Interface and General Operations

User Comment	Resolution
How should *ArchaeoFusion* mange variable data value units and resolutions?	*ArchaeoFusion* will retain original data values and operations will operate only on original data values in all surveys. Tools will be provided to adjust mapping of those values to 0-1 for display. Dynamic range adjustment should be applied on request so that after an operation is run, a preset mapping is applied to the display (e.g. 2 standard deviations and gamma 1). This would almost eliminate the need for the stretch operation (although it should be retained).
Confusing Project/Survey interaction	Gray out "Edit Survey" or "Add Survey" until a project is created.
Templates required for operation are not accessible to non-administrator accounts	Templates are saved in *C:\Program Files\ArchaeoFusion*. Make write privileges part of install.
Operations provide a 1x1 filter size but this does not produce meaningful results	1x1 filter window size will be removed.
Filter window sizes should be defined in both ground units (meters) and samples since surveys have different resolutions.	Operations requiring filters query the survey resolution and automatically adjust between sample and ground size.
No indication of success after a project is saved.	Modifications create asterisk in *ArchaeoFusion* title bar. Saving removes asterisk.
On initial import, a layer is checked, but not visible. Un-checking and re-checking shows layer.	Logic was corrected in subsequent version.
Logic of layer ordering and display refresh was unclear.	When layer are reordered in the layer list, the display is updated.
Selecting a folder as project is unclear to many users. Would prefer a project file to select.	No modifications were made. Inspection of other software showed that this type of project storage is common and changes would have impacted other modifications.
No meta-data display for layers.	A meta-data display for surveys is added. Shows a variety of data (see User's Manual).
Range Match interface confused many users.	A new interface was added allowing the user to choose which tile to match against using a N, S, E, W arrow layout. The "All" selection is disabled. Users can make area selections and match against adjacent samples in the same tile.
Operations should close automatically after run.	Modifications to the operation stack made the interaction more intuitive.
When an existing project is loaded, the entire operation stack should not have to be rerun from the beginning.	The project folder was modified to maintain the current state of all operations when an *ArchaeoFusion* project is closed and opened.

User Comment	Resolution
When parameters of operations change, the user should be notified that the stack is not current. That is, what they see on the display does not represent the current stack.	A red light - green light is displayed near the Run Operation Stack button as an indicator of currency.
Clicking the "I" button of an inactive operation shows the result stored on disk. This is not intuitive since the user thinks that process is inactive.	The "I" and "H" buttons should be grayed-out if the operation is inactive. There seem to several issues related to the operation stack in which the order of saved operations is confused. The final configuration manages this problem by creating a more flexible approach to toggling operation results.
If an operation is unchecked, gray it out to make it more obvious to the user that it has been skipped over when the operation stack was last run.	Feature was added as part of the new operation interface.
Remove the need for a No-Op.	The No-Op operation renames as “reset” or “default” option
Toggle button to show grid lines with a specified spacing.	Added in the survey assembly tool.
Toggle button to show tile boundaries	Added to final version
Histogram windows are often hidden behind each other and behind the main AM window.	All histograms are now displayed in the right-hand pane.
Move display controls to Split Pane on the right. Move histogram to this pane.	The existing *ArchaeoFusion* right-panel now contains a variety of meta-data displays and controls
Add ability to change color of shards.	Available in the final version
Prefer ability to load GeoTiff formatted images and DEMs	The ability to reference image data and terrains is part of the current version.
Zoom to Survey needs to adjust eye point and reorient to North is Up. Center of screen needs to be centroid of survey, not origin.	Overall navigation modified to accommodate this request.
Right hand screen *Smooth* button shows tile boundaries.	OpenGL display was modified to interpolate across tile boundaries.
Colormaps do not have enough entries to show find detail	256 element colormaps are used by default for all colormaps.
Add more colormaps. Particularly have one that is a reverse gray scale, but with all values beyond min/max displayed as blue/red.	Added to final version.
Allow colormaps to be reversed	Added to final version.
New surveys should be added to an existing shard if possible. Even number of active shards do not allow for highlighting.	Added to final version.

User Comment	Resolution
Band calculator: add Boolean logic, power, square, max and min functions to calculator. Min and max will take the max data value of multiple bands in a given location. Syntax might be max(B1,B2,B3) or min(B1,B5).	A more complete set of operators are provided in the band calculator in the current version of AF.
Band calculator: A false expression such as "6B195" returns a result.	Nonsensical input data now produces an error.
Allow user enter values to exaggerate a height map.	Added to final version.
When a recently fused survey is opened in the Survey Editor, it displays with no data values (gray, black, maybe). The originating survey is unaffected.	This is due to the lack of a mapping from data values to 0-1. Corrected in a later version.
1D Fourier and 2D Fourier operations can easily cause catastrophic crash of *ArchaeoMapper*. Need to make the viewer inactive while user is working in the filter window, and make sure the filter window is closed to bring user back to viewer.	These issues surrounding the 1D and 2D Fourier interactive dialogues were corrected in the final version.
Rename Fuse Surveys Tool function does not make sense when breaking apart surveys.	This function was renamed to better reflect its functionality.
Add options to Fuse Survey Tool such as an option to retain tile information or merge into a single "image". Perhaps a resample option.	When fusion or breaking apart surveys, the user is many options including those requested during the beta test.
Rename Band_0, Band_1 based on the measurement type from the file header. If a name doesn't exist, then use B1, B2, etc. to be consistent with the Band Calculator. Layer/survey entries should be show band labels (B1, B2, etc.).	Layer bands names can now be renamed and are, by default, named B1, B2, etc.
It is hard to tell if Band buttons (B1, B2, etc.) are depressed or not.	Contrast was improved but is also dependent on the operating system.
Export survey to SURFER grid format.	Export to SURFER grid format was added in a later version.
Digitize points (latitude/longitude) in survey for export to text file and possibly as GPS waypoint file. This is also a way to output locations of anomalies for planning excavations.	This feature request was beyond the scope of this effort but is noted as a possible addition to the software.
Export to KML for quick sharing and review.	This Export option was not added in favor of a more general GeoTIFF export.
Layout view with ability to add north arrow and scale bar.	Export options for a reporting format include a north arrow and scale bar.

User Comment	Resolution
Compile all Matlab functions as a Java Package (need Java Builder for Matlab).	This level of integration, made available in version R2010a of Matlab and preferred over the earlier integration techniques used in AF, required enough changes that the development team delay the upgrade until Version 2.0 of AF.
Organize toolbar. Add tool-tips with full operation name and short description	The tool bar was reorganized and hover tool tips added.
GPS import. How to do this? Interpolation?	Data files with GPS references are imported with the user selecting the sample size. GPS data is interpolation to the chosen grid.
Measuring tool is needed (distance, area, angle).	Interactive measurement tools will be added in a later version of AF.
Difference button - make it so that it shows the difference between two places in the operation stack that the user selects. Or at least make it so it shows the difference for the last operation done, not the last in the stack.	Added to the right hand pane and integrated into the operation stack so that the difference between any two operations can be displayed.
Difference button - Make it so that it does not disappear when mouse is not close, and so you can tell that it is on or off.	Corrected in a later version of AF.
Add buttons to toolbar for creating a new survey or editing a survey.	Added to the final version.
Allow selection of multiple contiguous tiles using a box rather than clicking each one individually.	Added to the final version along with more intuitive and reactive tile selection.
Add labels to the values displayed for pixels when you click in the viewer.	An enhanced query tool now displays all know information about a selected data sample.
Allow user to add a previously created survey to the current project.	Added to the final version.
Toggle button to show tile labels in the viewer and survey tool.	Added in the final version.
Add a log file to show everything the user has done.	All processing steps are recorded in the project file and may be viewed an any time. History logs are maintained, however.

Table 2-2. Beta Test Comments and Resolutions: Survey and Tile Editor

User Comment	Resolution
Need to add "feet" vs. "meter" choice to Survey Tool. In particular multiple units should be used throughout the interface	*ArchaeoFusion* users are allowed to define the projection and units of the data on import and after a project has been created.
Add “Auto Assemble” tiles if X, Y values represent survey coordinates.	This approach was discussed but ultimately not implemented because of the potential for confusion in the file names and the difficulty associated with naming the tile files with a particular convention. Essentially, users concluded that it was easier to manually add the tiles in the Survey Editor.
Change initial snap size to 2m in Survey Editor.	Added to the final version.
When snap size is changed, the blue grid does not change. The show grid button must be un-clicked and clicked.	Corrected. NOTE: The interface and architecture of the Survey and Tile Editor was substantially changed after the beta test due the number of inconsistencies and errors encountered.
Add ability to select/shift/move multiple tiles in Survey Tool.	Feature added to the final version.
In Survey Editor, may the origin more obvious. Brighten yellow lines, add text, datum mark, etc.	Graphics in the Survey Editor were substantially overhauled to make navigation and interaction more intuitive in this user intensive component.
Survey tool crashes on Tile Rotate.	Corrected.
Tile Editor Undo causes catastrophic crash of AM.	Corrected.
Survey Editor navigation control should be similar to Survey Viewer.	Added in the redesigned Editor.
Some data sets (EM, maybe others) come in to viewer reversed (min data value is mapped to 0, not 1).	Consistent data mapping are enforced.
Add ability to toggle tile name display in the Survey Editor and the Survey Viewer.	Added in the redesigned Editor.
Standardize slice names to reflect depth range.	A GPR related change, added in the redesigned Editor.
In the tile editor tool, lines shifted to the left loose forever values shifted off the tile. This can't be repaired with subsequent shifts to the right.	Corrected in the redesigned Editor.
GPR Slicing: Down-sample when creating slices and give participants options for how to do this: nearest neighbor, averaging, etc. A good default would be 8 pixels per meter in the traverse direction, using pixel aggregation or averaging (to avoid smoothing).	GPR related, multiple options for slice construction are available in the redesigned Editor.
Tile Editor "reset" button. Add text to tell the user that this will put the origin in the lower-left corner.	Similar functionality added in the redesigned Editor.

User Comment	Resolution
Tile Editor: Need a clearer indication that the tile is selected when you are going to alter the size, etc. Currently a blue box is drawn, but then it disappears when you move your mouse to the "Alter tile" button.	Added in the redesigned Editor.
Tile Editor: Rather than "none" button, use a black arrow or something more intuitive.	Added in the redesigned Editor.
Tile Editor: When you open the survey tool to create a new survey, it should open with the default values, not the previous settings - especially the survey name.	Added in the redesigned Editor.
Load Tile dialogue box: once you select a template - you cannot unselect it.	Corrected in the redesigned Editor.
Icons for rotating and flipping (mirroring) tiles are not clear. Add pop-up text?	Added in the redesigned Editor.
Survey Tool: Need for some indication that a tile has been rotated or flipped.	This information is stored in the tile metadata.
Adding tiles: “When you first enter the add tiles window it prompts you to enter the parameters and hit ‘next’ on a couple of screens. After the second next it prompts you to save your template. As soon as you hit save it opens a windows-based explorer pop-up. The system expects you to select tiles to use to populate your template, but in the sequence of events that leads to this window it seems like you should be searching for somewhere to save your template. I found this confusing. It seems that there ought to be some sort of prompt to search for raw data prior to the windows explorer pop-up.”	This behavior is corrected and improved in the redesigned Editor.
Survey Tool: For changing the tile size in the survey tool: In tutorial #2 the GPR surfer grids were slightly smaller than they were supposed to be, so we had to resize. The size as listed in those boxes had several decimal places, and the numbers were displayed so that you could not see the number from the left (you could only see the last few digits on the right). So you have to put your cursor in each box and use the back arrow key to see the original number. So these numbers need to load so they are left-justified, and probably with fewer decimal places.	Corrected in the redesigned Editor.

Table 2-3. Beta Test Comments: GPR Editor and Wizard

User Comment
GPR should be able to handle perpendicular tiles, but not in tiles.
Should we try to handle GPR obstacles?
Incorporate topographic correction.
GPR Wizard: out of memory problem (will be solved with Java/Matlab interaction change).
GPR Wizard: window too large if profiles are long (will add scroll bar to window)
GPR Wizard: ways to rearrange profiles other than little arrows
GPR Wizard: show individual traces rather than mean trace when gaining
GPR Wizard: Annotate velocity curve points with depth, time, velocity, and relative dielectric permittivity.
GPR Wizard: slice thickness slider bars should have a scale in ns and meters, not just samples 0-511.
GPR Wizard: Vertical filter
GPR Wizard: Gaining step(s) could be eliminated until the last step if display gains are added so the use can adjust gains as needed while going through each step.
GPR Wizard: for distance normalization between marks, allow user to input number of traces per meter. Use pixel aggregation (averaging) rather than pixel thinning (resampling) if possible.
GPR Wizard: export 3D cube in generic formats for bringing into other programs.
GPR Wizard: Time zero correction should optionally operate on each trace, or the average trace per profile.
GPR should be able to handle perpendicular tiles, but not in tiles.
Should we try to handle GPR obstacles?
Incorporate topographic correction.
GPR Wizard: out of memory problem (will be solved with Java/Matlab interaction change).
GPR Wizard: window too large if profiles are long (will add scroll bar to window)

2.2.3. *ARCHAEOFUSION* VERSIONS 0.91 – 1.0 (MARCH 2009 – MAY 2011)

From March 2009 to May 2011, the *ArchaeoFusion* development team focused on creating a new 2D and 3D GPR processing interface based on comments listed in Table 2-3. Jason Herrmann, an Environmental Dynamics Ph.D. Candidate at the University of Arkansas provided significant commentary on the GPR processing component. Several other users provided feedback through email. Informal testing was conducted in the context of two field schools in Amarna, Egypt in February 2011 and Kampsville, IL in June 2010. The current design of the GPR Processing component, as described in the User's Manual, was developed and implemented during this time.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY/METHODOLOGY

Currently, characterizations of subsurface deposits and evaluations of a site's NRHP eligibility status are based on the results of hand excavation. Details vary from state to state, but in general, pedestrian survey or shovel-tests are used to identify sites and define their boundaries. Site integrity is typically based on an evaluation of stratigraphy documented by small excavation units. This approach's reliability is strongly dependent on sampling, although this is often not specified. For example, one can visualize a site that covers .5 ha (5,000 m^2) and contains 100 subsurface pit features (commonly used in prehistory for storage, cooking, processing, and ultimately, trash discard), each less than one m in diameter. In many regions, this type of site might be evaluated using shovel tests spaced at 15 m intervals and 5 or so 1 by 1 m test units. Based solely on probability, it is easy to imagine that this approach could fail to intersect any subsurface features. That failure could easily lead to unfortunate management decisions, such as failure to protect genuinely important resources; (the worst case scenario is the inadvertent discovery of human remains that results in project delays, confrontation with stakeholder groups, etc). Another risk (likely a common occurrence) is that CRM professionals, aware of the unreliability of traditional site evaluation approaches, sometimes choose to err on the side of caution by advocating avoidance of sites that don't warrant such protection. Such unwarranted avoidance may not inconvenience some agencies, but site avoidance is a major obstacle to realistic military training.

The geophysics-based alternative to the traditional site evaluation approach currently requires the old, ad-hoc approach described above, involving a host of different software programs, and disadvantaged by the loss of data resolution and metadata when shifting among them. The processing time required is too much, and integration of the results is rarely possible without additional resources and expertise. Table 2-4 describes the relative advantages and disadvantages of these approaches.

Table 2-4: Advantages and limitations of alternative approaches to evaluating archaeological sites.

Method: **Advantages/disadvantages**	**Traditional excavation**	**Geophysical approach using COTS software**	**Integrated multi-sensor approach using *ArchaeoFusion***
Equipment cost	Hand tools (negligible cost)	Ca. $20k per sensor	Ca. $20k per sensor
Labor cost for small sites	Less than geophysical	More than traditional	More than traditional
Labor cost for large sites	More than geophysical	Less than traditional	Less than traditional
Expertise required	Less than geophysical	Strong expertise required	Modest expertise required
Curation costs	More (proportional to amount of excavation)	Less (less excavation = less curation)	Less (less excavation = less curation)
Portion of site examined	Very little	Much more	Much more
Reliability of interpretations	Lower than geophysical	Greater than traditional	Much greater than traditional
Damage to site deposits	Greater than geophysical	Less than traditional	Less than traditional

2.3.1 MAJOR COST CONSIDERATIONS

For the traditional approach to site evaluation, the major cost factor is labor. CRM personnel are not highly paid by the standards of professions such as engineering; (applicability of the Service Contract Act, however, means that archaeological work on federal lands is often much more expensive than similar work done elsewhere). However, all aspects of archaeological work are labor intensive. Archaeological excavation involves hard physical labor under conditions that are often uncomfortable, as well as detailed mapping and attention to detail. Analysis and publication require familiarity with a large body of comparative literature, classification systems, etc. Perhaps the most important issue is that the costs of traditional archaeology will gradually increase, but there is little likelihood of increases in efficiency based on current practices. For the geophysical approach to site evaluation, the primary cost factor is equipment purchase. The most widely used sensors (GPR, magnetic, electrical resistance, conductivity) each cost between ca. $15K and $25K. A second cost factor is the need for at least some training in collecting, processing, and interpreting geophysical data. Individuals who can competently conduct geophysical surveys are typically somewhat (but not extremely) more highly paid than traditional archaeologists. However, as archaeologists become more familiar with "high-tech" applications like geophysics, the gap in pay between geophysical practitioners and other archaeologists is likely to narrow. More important, however, is the likelihood that geophysical sensors will become less expensive relative to their capabilities (much like the trend in personal computers). Technological improvements are also likely to make geophysical instruments more cost effective in terms of the area that can be investigated per hour or day. Examples include GPR units mounted on carts with self-contained batteries and graphic capabilities, and electrical resistance

(which has traditionally been the most physically demanding technique) sensors mounted on carts that can be towed by All Terrain Vehicles (ATV). Improvements in the memory capacity of data recorders and the performance of batteries will allow additional improvements in performance and reductions in cost. In short, traditional archaeology is not likely to become more cost efficient whereas "high tech" archaeology (including geophysics) is virtually certain to do so.

3.0 PERFORMANCE OBJECTIVES

An important component of this project was to assess eight performance objectives, which were developed to demonstrate and validate the cost and performance benefits of the multisensor geophysical approach and the technology infusion tool (*ArchaeoFusion*). An initial performance assessment (Assessment 1) of *ArchaeoFusion* was conducted during the first quarter of 2011. A second ESTCP-approved assessment (Assessment 2) was conducted in the third quarter of 2011 to make up for insufficient results in Assessment 1 due to lack of user participation and provision of results. Both assessments were conceived by the *ArchaeoFusion* team (Jackson Cothren, Michael Hargrave, and Eileen Ernenwein), with Ernenwein serving as the expert practitioner and user of *ArchaeoFusion* (hereafter referred to as the "*ArchaeoFusion* expert") who processed all of the control data and served as the main contact for all participants. While these assessments took place in computer labs and office environments, a major aspect of this project was the validation of the multi-sensor geophysical approach to site evaluation, which was accomplished during the field component conducted at Los Adaes State Historic Park in Louisiana during the third quarter of 2008 and the second quarter of 2009 (see Sections 4 and 5.4.2).

3.0.1 ASSESSMENT 1

Assessment 1 was originally planned as a group session, much like the beta test, but conflicting participant schedules made this impossible. The assessment was therefore done remotely so that each participant could complete it on their own time. Detailed instructions (Appendix C) and a worksheet for reporting results (Appendix D) were provided. A total of 53 current or prospective users were invited to participate, including all members of the user group, all users currently signed up as beta testers, and others in the field of archaeological geophysics. Three months were allowed, but in the end only four users sent in their results, and not all of them were complete (all results are given in Appendix E). This severely limited this Assessment 1.

All eight of the Performance Objectives were evaluated, where possible, by comparing observed counts, percentages, and times to predicted values (Table 3-1). Evaluation of Performance Objectives 1 and 2 focuses on the number of anomalies identified and observed versus predicted related to Type 1 (false positive) versus Type 2 (false negative) errors. Performance Objectives 3 and 5 were evaluated based on the percentage of control anomalies (i.e., anomalies selected because they are, to varying degrees, challenging to detect) detected in *ArchaeoFusion*-processed data. The control anomalies were identified in datasets processed in *ArchaeoFusion*, but without use of *ArchaeoFusion's* "wizards" (processing guidance for non-expert users). Those Performance Objectives quantify the extent to which use of the software's wizards allow non-expert users to achieve processing results comparable to those of an expert processor. Performance Objectives 4 and 7 were evaluated based on differences in the amount of time required to accomplish specific processing tasks in *ArchaeoFusion* as compared to the leading commercial, off-the-shelf (COTS) software. Performance Objective 4 was also evaluated based on the percentage of positive user responses to standardized questions about *ArchaeoFusion's* capabilities. Evaluation of Performance Objective 6 was based on the amount of change in the number of data values per square meter present in datasets at the start and end of processing sequences. Performance Objective 8 was evaluated based on the percentage of feature anomalies

that are, based on the results of ground truthing investigations, correctly assigned to particular archaeological feature categories.

A number of the Criteria for Success used in Assessment 1 are predicted percentages, often predicted to be 100%. This expected value is not arbitrary; it reflects the expectation that positive results will be observed in all cases, but clearly provides a basis for quantifying deviations from this in the observed values. In several Performance Objectives, the Criteria for Success percentages are specified as 50% positive results. This value is somewhat arbitrary, reflecting an expectation that use of *ArchaeoFusion* will result in a substantial improvement in results achieved using COTS software. While 50% is somewhat arbitrary, the evaluation strategy provides a basis for quantifying the observed deviation from the expected.

Table 3-1: Performance Objectives and Results Summary for Assessment 1.

Performance Objective	**Metric**	**Data Requirements**	**Success Criteria**	**Results**
Quantitative Performance Objectives				
1. Non-integrated multi-sensor surveys provide more useful information than single sensor surveys	a) Total number of anomalies; b) total number of feature anomalies	a) Single sensor datasets; b) lists of anomalies and feature anomalies identified in single sensor datasets; c) number of datasets within which an anomaly is present at a particular locus.	a) Total number of anomalies and feature anomalies at least 50% greater in the combined datasets than in any single dataset; b) Deletion of anomalies appearing in only 1 dataset will reduce ratio of feature anomalies to anomalies by at least 50%.	(a) 85% success (b) 70% success (c) 100% success
2. Data integration increases potential for detecting archaeological features when compared to non-integrated data	a) Total number of feature anomalies detected; b) percentage of affirmative user responses to question #1; c) percentage of affirmative user responses to question #2	a) Non-integrated single sensor datasets; b) integrated datasets; c) participant responses to questions about *AF's* benefits.	a) Number of feature anomalies in integrated data is at least 50% greater than in nonintegrated data; b) 100% of user responses to question #1 about AF's benefits are affirmative. c) 100% of user responses to question #2 about AF's benefits are affirmative.	(a) Inconclusive due to lack of data, but see Table 3-2 for a reassessment. (b) 75% success (c) 100% success

Performance Objective	Metric	Data Requirements	Success Criteria	Results
4. Data processing using AF is faster and easier than using COTS software	a) Individual and aggregated processing times using AF; and b) using COTS software	a) Time required for processing tasks; b) user responses to standardized questions about AF's benefits	a) Time required to process using AF is at least 50% less than using (b) COTS software	Inconclusive due to lack of data, but see Table 3-2 for a reassessment.
5. Data from all major sensor types can be adequately processed using only *ArchaeoFusion*	a) Percentage of all control feature anomalies detected in datasets processed using only AF	a) 5 single sensor datasets processed using only AF	a) 100% of control anomalies detected in datasets processed using only AF	Inconclusive due to lack of data, but see Table 3-2 for a reassessment.
6. *ArchaeoFusion* preserves data resolution throughout processing	a) Data resolution (data values per square meter)	a) Information on data resolution at start and end of processing of 5 single sensor datasets and 3 integrated datasets	a) Data resolution is unchanged at start and end of processing of 5 single sensor datasets and 3 integrated datasets	100% success
7. AF reduces the time needed and increases the consistency and quality of metadata	a-b) Difference in amount of time necessary to record metadata, c) improvement in reproducibility of processing results.	a) Amount of time to record all metadata using COTS and manual systems, b) amount of time to record metadata using AF, c) comparability of analytical results using COTS and manual metadata and d) comparability of analytical results using AF and automated metadata, e) detailed processing metadata	(a) The mean time to record the metadata using AF will be at least 50% less than for the COTS software; (b) the mean time to reproduce the results of another participant will be at least 50% less using *ArchaeoFusion*; (c) the number of discrepancies in the nature or order of processing steps and in parameter values between two participants who used AF will be at least 50% less than for those using the COTS software.	Inconclusive due to lack of data, but see Table 3-2 for a reassessment.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
8. Ground truthing enhances the usefulness of geophysical data	a) Percentage of feature anomalies verified to be associated with archaeological features	a) List of anomalies categorized as feature anomalies based on data processed in AF; b) status of feature anomalies as actual features based on ground truthing results	At least 50% of inferences about feature anomalies being associated with actual archaeological features verified by ground truthing	80% success
Qualitative Performance Objectives				
3. *ArchaeoFusion* allows data integration	Number and percentage of control feature anomalies detected in integrated data	a) Non-integrated data; b) expert-integrated data not using wizards; c) user integrated data using wizards	100% of control feature anomalies detected in 100% of data integrated using wizards	100% success

3.0.2 Assessment 2

In attempt to solicit more feedback, the project team launched a new assessment (Assessment 2) that required substantially less time commitment. Assessment 2 consisted of an online survey (http://www.surveymonkey.com/s/S5YL22D, Appendix F) and a simplified version of the same tutorial used in the Assessment 1. The survey asked respondents to rate their level of agreement or disagreement with a series of statements, which mirrored the eight Performance Objectives. The last question requested comments about advantages and shortcomings of *ArchaeoFusion*. Users could easily answer these questions based on experience they already had using *ArchaeoFusion*, or by following along with the tutorial, which simultaneously helped them learn the software. The order of statements in the survey was altered from the original order of performance objectives to make them flow logistically with the tutorial. The survey questions and corresponding performance objectives were:

1. In regards to archaeological geophysics in general (regardless of software): multiple surveys, even when not integrated, provide more useful information than single sensor surveys. (Objective 1)
2. In regards to archaeological geophysics in general (regardless of software), data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc) increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets. (Objective 2)

3. *ArchaeoFusion* allows users to effectively integrate data from multiple sensors (i.e. overlays, translucent overlays, band calculator, principle components analysis, and k-means cluster analysis). (Objective 3)
4. Data from all major sensor types can be adequately processed using *ArchaeoFusion* alone. (Objective 5)
5. In comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers (i.e. GPR, EMI, magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. (metadata is the information about your data, such as what instrument was used to collect it, the start corner and direction for the survey, etc.). (Objective 7)
6. *ArchaeoFusion* preserves data resolution. (meaning, that when you are finished processing your data, you can always revert to the original data with the original data density). (Objective 6)
7. Data processing using *ArchaeoFusion* is faster and easier than processing using other COTS (commercial off-the-shelf) software. (Objective 4)
8. Ground-truthing (test excavations to evaluate interpretation of geophysical data) enhances the usefulness of geophysical data. (Objective 8)
9. Please comment on the benefits of *ArchaeoFusion* and describe any shortcomings that you perceive.

Table 3-2 summarizes user responses to questions 1-8. The categories “strongly disagree” and “disagree” in the original survey were combined, as were “agree” and “strongly agree”. Respondent 3 wrote in the comments that he or she had never used *ArchaeoFusion*. Assuming that the respondent is familiar with archaeogeophysics, we have counted those survey answers for questions 1, 2, and 8, but not 3-7, for which “neutral” was marked. Comments written in question 9 are given along with individual survey results in Appendix B, and also quoted where appropriate in the discussion of each Performance Objective. Individual respondent names have been omitted in this report to protect privacy.

Table 3-2. User Responses to questions 1-8 in Assessment 2

Question (Objective)	**Disagree**	**Neutral**	**Agree**	**Response Count**
1 (1)	0	0	**100% (14)**	14
2 (2)	0	0	**100% (14)**	14
3 (3)	0	8% (1)	**92% (12)**	13
4 (5)	31% (4)	23% (3)	**46% (6)**	13
5 (7)	0	46% (6)	**54% (7)**	13
6 (6)	0	0	**100% (13)**	13
7 (4)	8% (1)	31% (4)	**61% (8)**	13
8 (8)	0	14% (2)	**86% (12)**	14

Table 3-3 lists the performance objectives and results for Assessment 2, using the same table format as Table 3-1. These results, combined with the results of Assessment 1 serve as a thorough evaluation of the eight performance objectives. A detailed analysis of these results is given in Section 6: Performance Assessment.

Table 3-3: Performance Objectives and Results Summary for Assessment 2.

Performance Objective	**Metric**	**Data Requirements**	**Success Criteria**	**Results**
Qualitative Performance Objectives				
1. Non-integrated multi-sensor surveys provide more useful information than single sensor surveys	Responses to Survey Question #1.	Participant must have general knowledge of archaeological geophysics.	Greater than 50% agreement	100% agreement
2. Data integration increases potential for detecting archaeological features when compared to non-integrated data	Responses to Survey Question #2.	Same as above.	Greater than 50% agreement	100% agreement
3. *ArchaeoFusion* allows data integration	Responses to Survey Question #3.	Participant must have experience integrating data in *ArchaeoFusion*.	Greater than 50% agreement	92% agreement
4. Data processing using AF is faster and easier than using COTS software	Responses to Survey Question #7.	Participant must have experience processing data in *ArchaeoFusion* and other comparable software.	Greater than 50% agreement	61% agreement
5. Data from all major sensor types can be adequately processed using only *ArchaeoFusion*	Responses to Survey Question #4.	Participant must have experience processing all major data types in *ArchaeoFusion*.	Greater than 50% agreement	46% agreement
6. *ArchaeoFusion* preserves data resolution throughout processing	Responses to Survey Question #6.	Participant must check the resolution of their data in *ArchaeoFusion* before and after processing.	Greater than 50% agreement	100% agreement

Performance Objective	Metric	Data Requirements	Success Criteria	Results
7. AF reduces the time needed and increases the consistency and quality of metadata	Responses to Survey Question #5.	Participant must have experience processing data in *ArchaeoFusion* and other comparable software.	Greater than 50% agreement	54% agreement
8. Ground truthing enhances the usefulness of geophysical data	Responses to Survey Question #8.	Participant must have experience ground-truthing geophysical data.	Greater than 50% agreement	86% agreement

3.0.3 Description of Performance Objectives

Objective 1

Non-integrated multi-sensor surveys provide more useful information than single sensor surveys.

Discussion: This performance objective demonstrates to potential users the benefits of using data from multiple sensors, even when those data are not integrated. Given the purchase cost of geophysical instruments, novice practitioners are often tempted to rely on only one sensor. Single-sensor surveys (of appropriate sites) are much better than a reliance on traditional approaches, but the use of multiple sensors confers several important advantages. Multiple sensor surveys typically result in the detection of a larger number of anomalies, a wider range of anomaly types, and provide more information about the characteristics of archaeological features associated with the anomalies. Anomalies that occur at a particular locus in more than one type of data are more likely to be associated with an archaeological feature (although other causes remain possible) than are anomalies that occur in a single dataset. We use the term “feature anomaly” to indicate that a particular anomaly is believed to be associated with an archaeological feature. Individually or as a group, feature anomalies are likely to play a role in management decisions about a site, including its eligibility for nomination to the NRHP, where ground truthing excavations should be located, etc. Anomalies that are not categorized as feature anomalies may or may not be associated with features.

In evaluating this performance objective, we considered two types of error. Type 1 errors represent a failure to detect feature anomalies that should be considered in decisions about site management. Detecting a larger number of anomalies (which can be achieved by using multiple sensors) reduces the likelihood of Type 1 errors. Minimizing Type 1 errors often increases the occurrence of Type 2 errors--detecting anomalies that are not associated with archaeological features. The negative aspect of Type 2 errors (also called “false positives”) is that they can lead to the expenditure of funds for ground truthing, or contribute to inappropriate management decisions (e.g., protecting a site based on an abundance of anomalies that are, in fact, not associated with features). Fortunately, multiple sensor surveys can also help reduce the occurrence of Type 2 errors. Anomalies that occur only in one of several datasets are less likely to be feature anomalies than those that occur in two or more datasets.

Metric: (a) Total number of anomalies; (b) total number of feature anomalies.

Data: (a) Single sensor data sets (n=5) processed by the project team's *ArchaeoFusion* expert; (b) lists of anomalies and feature anomalies identified in the single sensor datasets by the evaluation participants; (c) information on the number of datasets within which an anomaly occurs at a particular location.

Criteria for success: Type 1: (a) the total number of anomalies identified in five combined single sensor datasets will be at least 50% greater than the number identified in any single dataset; (b) the total number of feature anomalies identified in the five (combined) datasets will be at least 50% greater than the number identified in any single dataset. Type 2: (c) Deletion of all anomalies that appear in only one of the five single sensor datasets will increase the ratio of feature anomalies to anomalies by at least 50%.

Objective 2

Data integration increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets.

Discussion: This performance objective demonstrates the benefits in information return that result from integrating data from multiple sensors. Data integration typically has two important advantages over the use of single sensors or multiple but non-integrated sensor data. 1) Integrated data often reveal the presence of feature anomalies that are not readily discernible in non-integrated data. 2) Integrated data nearly always provides information about the characteristics of features that would not be easily discerned in non-integrated data. Such information often plays an important role in selecting anomalies for ground truthing, and in interpreting feature anomalies that are not ground truthed based on those that are investigated. For example, consider the detection of the subsurface remains of a prehistoric house with a central hearth using resistivity, magnetic gradiometry, and magnetic susceptibility (MS). Resistivity would probably detect the walls but not the central hearth, indicating that the walls are composed of material that retains more or less moisture than the surrounding matrix. Suppose MS data also shows the walls, confirming their existence and suggesting that they have a magnetic component. The MS data might also show an anomaly near the center, indicating a possible hearth or pit feature. Magnetic gradiometry might show a strong anomaly in the center associated with the hearth, but not the walls. This suggests that the walls are weakly magnetic, but were not burned. Burning would leave a remnant magnetic field that is only detectable with a magnetometer (but not by MS). The strong anomaly in the center is most certainly a hearth because it is detected by magnetic gradiometry and is located in the center of the house. In summary, both MS and magnetic gradiometry are needed to deduce the presence of subsurface house remains constructed of materials that are magnetic but not burned in situ, with a hearth at its center. The addition of the resistivity data adds weight to the presence of the walls, and suggests that they were constructed of a material that retains more or less moisture than surrounding soils. When the three datasets are integrated, these relationships become more prominent than when the datasets are considered separately.

Metric: a) Total number of feature anomalies detected (using *ArchaeoFusion*); b) Percentage of affirmative participant responses.

Data: a) Non-integrated single sensor data for each of the five data types processed by the project team's *ArchaeoFusion* expert, and b) the integrated data processed by each evaluation participant using *ArchaeoFusion*. c) Participant responses to standardized questions focused on whether the use of *ArchaeoFusion* to integrate data (1) increases one's ability to detect feature anomalies and (2) provides information that is not available from data processed in *ArchaeoFusion* but not integrated.

Criteria for success: (a) The total number feature anomalies detected by evaluation participants in the integrated data is at least 50% greater than the total number of feature anomalies detected in the non-integrated datasets. (Recall that feature anomalies are only those judged likely to be associated with features). (b) 100% of participant responses indicate that the detection of feature anomalies is facilitated by data integration using *ArchaeoFusion*; (c) 100% of participant responses indicate that the characteristics of feature anomalies are more readily apparent because the datasets are integrated using *ArchaeoFusion*.

Objective 3

ArchaeoFusion allows all users to effectively integrate data from multiple sensors.

Discussion: This performance objective will demonstrate that *ArchaeoFusion* provides all users with the capability to effectively integrate data from multiple sensors. Very few archaeo-geophysical practitioners currently integrate data by means other than simple graphical overlays of two data sets. None of the software widely used by archaeologists (Geoplot, ArchaeoSurveyor, Radan, and GPR Slice) has even these basic data integration capabilities, necessitating use of another software package that allows overlaying images in a GIS-like environment. By nature of its design, *ArchaeoFusion* allows simple data integration because all datasets are added as layers as they are in a GIS. Many archaeologists have little background in the statistical (e.g., principal components) and mathematical techniques that underlie *ArchaeoFusion's* integration methods. Despite these circumstances, *ArchaeoFusion's* integration wizards will guide users at all levels of experience to effective integrations of data from multiple sensors. *ArchaeoFusion's* integration capabilities will be an incentive for some users to become more familiar with integration techniques, and this will help archaeological geophysics move a step forward.

Evaluation of this performance objective requires an objective determination that data integration using *ArchaeoFusion's* wizard is properly done. The project team's *ArchaeoFusion* expert will first process selected portions of the five single-sensor datasets using *ArchaeoFusion* and then integrate them *without* using *ArchaeoFusion's* integration capabilities. The five datasets will be integrated using at least three of the integration methods provided by *ArchaeoFusion*. The integrated data feature anomalies will then be assigned to one of three categories, ranging from category 1 (high contrast feature anomalies that are easy to identify) to category 3 (low contrast feature anomalies that are challenging to identify). The expert results will serve as the control. The five individual datasets processed (but not integrated) by the expert will be provided to the evaluation participants, who will be asked to integrate those datasets using *ArchaeoFusion's* integration wizard using the same three integration methods. The control feature anomalies assigned by the expert to the three categories will be used to evaluate the adequacy of the datasets integrated by the participants using *ArchaeoFusion's* integration wizard. If the wizards

do a good job in integrating the data, then all of the control anomalies will be visible (including those categorized as challenging to identify). If the integration wizards do not perform well, it will not be possible to identify each of the control feature anomalies.

Metric: The number and percentage of control feature anomalies (in categories ranging from easy to challenging) that can be identified in data integrated by the participants using *ArchaeoFusion*'s integration wizard

Data: a) Non-integrated single sensor datasets processed by the project team's *ArchaeoFusion* expert; b) integrated datasets produced by the expert using three different methods but without relying on *ArchaeoFusion*'s wizard; c) datasets integrated by each of the evaluation participants using *ArchaeoFusion*'s wizards and the same three methods used by the expert.

Criteria for success: 100% of the control anomalies (those assigned to the three categories ranging from easy to challenging) can be detected in 100% of the datasets integrated by the participants using all three of *ArchaeoFusion's* wizards.

Objective 4

Data processing using *ArchaeoFusion* is faster and easier than processing using COTS (commercial off-the-shelf) software.

Discussion: If *ArchaeoFusion* is to contribute to a much wider use of the integrated multi-sensor approach to site characterization, it must be easier (as well as, faster) to learn and use than the existing software. A new group of five evaluation participants will be recruited from UA-F anthropology students including those who have <u>previous experience</u> in processing geophysical data. Tutorial 2, used in the *ArchaeoFusion* beta test, will be used here. A very similar Tutorial (with the same processing goals) will be developed for the three leading COTS software packages (ArchaeoSurveyor, Geoplot, and Radan). The student evaluators will be requested to use *ArchaeoFusion* and one or more of the COTS software to accomplish the same basic processing tasks. The time required for each evaluator to accomplish each task will be documented. The evaluators will then be asked to respond to standardized questions that focus on *ArchaeoFusion*'s ease of use relative to the other software.

Metric: Aggregated and individual times for the completion of specified processing tasks using (a) *ArchaeoFusion* and (b) COTS software.

Data: (a) Time required for student evaluators to accomplish basic processing tasks using *ArchaeoFusion* and COTS software. (b) Student evaluator's responses to standardized questions concerning the ease of use of each software package.

Criteria for success: (a) Times required to accomplish processing tasks using *ArchaeoFusion* are 50% less than times associated with the other software packages. (b) 100% of the responses to standardized questions indicate (by choosing values 1 or 2) that *ArchaeoFusion* is easier to use than COTS software.

Objective 5

Data from all major sensor types can be adequately processed using only *ArchaeoFusion.*

Discussion: For most potential users, one of the impediments to integrated multi-sensor surveys is the need to purchase, learn, and use multiple software packages. This performance goal will demonstrate that *ArchaeoFusion* is the only software needed to adequately process the five major types of geophysical data widely used in the US for archaeological applications. Evaluation of this performance objective requires an objective determination that particular data sets have been adequately processed. In this evaluation, the data processing has two major goals: (1) remove or subdue data defects created by surveyor errors or field conditions, and (2) enhance the visibility of feature anomalies. Achieving these goals requires a unique processing sequence for each dataset. Selected areas of each of the five single sensor datasets will first be processed by the project team's *ArchaeoFusion* expert using only *ArchaeoFusion*. The expert will examine each of the five single sensor datasets and identify a) the main defects that must be removed, and b) a small number of relatively subtle (in geophysical terms, low contrast) control anomalies. The control anomalies will be assigned to the same three categories (ranging from easy to challenging to detect) as described in Objective 3.The same five datasets will then be processed (using only *ArchaeoFusion*) by the evaluation participants. Their results will be categorized as adequately processed if all of the defects are adequately removed or subdued and the control anomalies assigned to all three categories are discernible.

Metric: Percentage of all control feature anomalies detected

Data: The five single-sensor datasets processed by all evaluation participants using only *ArchaeoFusion*.

Criteria for success: 100% of control features detected in 100% of datasets processed by evaluators using only *ArchaeoFusion*.

Objective 6

ArchaeoFusion preserves data resolution.

Discussion: This objective demonstrates one of *ArchaeoFusion's* important capabilities in the area of data management. During data collection, experienced practitioners select the number of data points to be collected per square meter (data density) in response to site conditions, the type of deposits one hopes to detect, and time constraints. Data collected by different sensors typically have different data densities, and sometimes a surveyor changes the sampling density during a survey using the same instrument or geophysical method. Processing individual datasets without *ArchaeoFusion* requires that all parts of the dataset have the same data density, and integrating data without *ArchaeoFusion* requires resampling to achieve a consistent pixel size for all parts of all datasets. Resolution is lost when resampling involves a reduction in data density, and data processing artifacts can be introduced when data are resampled to a greater data density before they are fully processed. Using other software products, the user must separately process all datasets or portions of datasets that have different resolutions, and then resample to a common resolution and add them together in a GIS before they can even view entire surveys and overlay them with other datasets. *ArchaeoFusion* allows the user to fully process data with different data densities, (even within the same survey or data layer); with the result that no data resolution is

lost and no interpolation artifacts are introduced. In addition, *ArchaeoFusion* allows integration of datasets by overlay methods (e.g., translucent overlays) without resampling. Integration methods that rely on direct comparison of pixels from one dataset to another (e.g., principal components analysis, maximum function, K-means cluster analysis) by nature require that all layers are resampled to the same resolution, so *ArchaeoFusion* automatically resamples the data when these operations are run, and a new image is generated. Thus, the original datasets retain their sampling densities, while the integrated results are saved separately.

The project team's *ArchaeoFusion* expert will modify each of the five single sensor datasets so that each includes areas with two different data densities. Each of the evaluation participants will process each of the five modified single sensor datasets and then integrate those datasets using three of *ArchaeoFusion's* integration methods. The participants will document data density at the start and conclusion of each of these processing sequences, including the integrated datasets.

Metric: Data resolution (data values per square meter).

Data: Information on the data density at the start and end of processing for each of the five single sensor data sets processed by each evaluation participant.

Criteria for success: The data resolution at the end of a processing sequence will be the same as data resolution at the start of the sequence for 100% of the data sets processed by each of the evaluation participants.

Objective 7

ArchaeoFusion reduces the time needed and increases the quality and consistency of metadata for geophysical data.

Discussion: A precise record of the steps used in processing data is emerging as an important requirement for digital geophysical data deposited in federally approved archives under 36CFR79. All currently available geophysical processing software systems used by archaeologists have limited capabilities to automatically record metadata. Without *ArchaeoFusion*, maintaining a record of the complex sequence of processing steps and parameter values required by data integration is done manually and is, at best, idiosyncratic and very time-consuming. At worst, there is a likelihood of inaccurate or incomplete metadata. *ArchaeoFusion* preserves the sequence and parameter values of processing steps, allowing the user to systematically alter parameters until the best result is obtained. This metadata is preserved and can be consulted at any time to see exactly what steps have been taken. With *ArchaeoFusion* the raw instrument data and data processing stack can be archived, allowing any future researcher to duplicate the results.

A control group of UA-F graduate students including ones with previous experience in processing geophysical data will record all necessary steps to fully process two single sensor datasets using COTS software packages with which they are already familiar. The evaluation will focus on conductivity and GPR data, which require more complex processing than other data types. The time required to process each of the datasets and to fully document the sequence of processing steps and parameter values (using the COTS software) will be recorded. The raw data processed by Student 1 will then be provided to Student 2, and Student 2 will be asked to reproduce the results (and record the time expended) using the same (COTS) software. The

external review evaluation participants will then be asked to do the same processing tasks on the same datasets using *ArchaeoFusion*. The processing time and the time needed to prepare the metadata for archiving will be recorded. The raw data and *ArchaeoFusion* "processing stack" from participant 1 will be given to participant 2 who will be asked to reproduce the results. The outcomes will be compared and the time required to perform each task will be recorded.

Metrics: a-b) Difference in amount of time necessary to record metadata measured by comparing time required to accomplish each processing task and record metadata, and (c) improvement in reproducibility of processing results.

Data: (a-b) Time required for participants to accomplish each processing task and record metadata, (c) number of differences in processing steps and/or parameter values recorded in the metadata file.

Criteria for success: (a) The mean time to record the metadata using *ArchaeoFusion* will be at least 50% less than for the COTS software; (b) the mean time to reproduce the results of another participant will be at least 50% less using *ArchaeoFusion*; (c) the number of discrepancies in the nature or order of processing steps and in parameter values between two participants who used *ArchaeoFusion* will be at least 50% less than for those using the COTS software.

Objective 8

Ground truthing enhances the usefulness of geophysical data.

Discussion: This performance objective demonstrates how independent evidence can be used to confirm or reject one's interpretation of anomalies, thereby enhancing the reliability and usefulness of the geophysical data. Various types of data can be used in ground truthing: historic maps, photographs, local informants, and archaeological excavation. In this project we will rely on small scale, carefully targeted excavations and (to a lesser extent) the 1721 and 1767 historic maps.

Metric: Percentage of feature anomalies verified by ground truthing to be associated with archaeological features.

Data: a) Identification of anomalies as feature anomalies by each evaluation participant based on geophysical data he/she processed using *ArchaeoFusion*. 2) Status of feature anomalies as actual archaeological features based on results of ground truthing at Los Adaes State Historic Park, Louisiana.

Criteria for success: At least 50% of the inferences made by all evaluation participants that feature anomalies are actual archaeological features will be verified as correct based on the results of ground trothing at Los Adaes State Historic Park, Louisiana.

4.0 DEMONSTRATION SITE

This chapter provides a concise summary of the demonstration site, Presidio Los Adaes, including site selection criteria, location, history, facilities, and depositional integrity.

4.1 SITE LOCATION AND HISTORY

Los Adaes State Historic Site in west-central Louisiana was the project demonstration site. Criteria used to select Los Adaes were strongly influenced by the nature and requirements of the field demonstration and validation. Components of the demonstration included 1) a relatively large-area, multi-sensor geophysical survey; 2) use of *ArchaeoFusion* to process and interpret the resulting data; and 3) a small scale ground truthing excavation program to evaluate those interpretations. An additional important consideration was the need to conduct the demonstration in a venue that would be accessible to a substantial number of current and future geophysical practitioners and sponsors. The uncertainty of public access (in the event of future heightened levels of security) made it advisable to not hold the demonstration at a military installation. The National Park Service's annual week-long introductory course in remote sensing is perhaps the highest-profile venue regularly attended by leading geophysical practitioners, academic, public and private-sector CRM professionals. The project field demonstration was therefore scheduled to coincide with the 2009 NPS course. Los Adaes was selected to meet the needs of this project as well as the NPS course. This chapter describes site selection criteria, characteristics, and details of the project field demonstration during the NPS course.

4.1.1 SITE SELECTION

It was essential that the demonstration site have soil and vegetation conditions favorable to geophysical survey, as well as a wide range of archaeological deposits. The first requirement recognized that many—but not all—archaeological sites are suitable for the effective use of geophysical techniques. The second requirement for the demonstration site—the presence of a variety of archaeological feature types—was important to ensure a thorough assessment of the effectiveness with which *ArchaeoFusion* could be used to detect and interpret subsurface archaeological deposits based on their associated geophysical anomalies. Subsurface features or other targets can be detected if there is adequate contrast with their immediate surroundings in at least one of the properties measured by geophysical sensors (Ernenwein and Hargrave 2009; Kvamme 2001; Somers, et al. 2003). Other factors being equal, high-contrast targets are relatively easily detected whereas low-contrast targets may be relatively difficult or impossible to detect. To rigorously test *ArchaeoFusion*, it was important for high, low, and intermediate contrast targets to be present at the demonstration site. A third requirement for the demonstration site was that it must, by virtue of its archaeological character and history or prehistory, arouse the curiosity of a wide range of CRM professionals, including those who have not previously been exposed to, or interested in geophysics. Early on, we recognized that a historic fort might meet these requirements, particularly a relatively early fort that could, by virtue of its construction

using material other than brick or stone, only be effectively investigated by extensive excavation or small scale excavations guided by geophysical maps. Historic forts are evocative of frontier America and readily capture the interest of professional and avocational historians and archaeologists as well as lay persons with a casual interest in history.

Los Adaes was initially considered based on a recommendation by Louisiana Division of Archaeology (SHPO) State Archaeologist Dr. Charles McGimsey. McGimsey was already familiar with many of the factors that influence a site's suitability for geophysics based on Hargrave's geophysical investigations at several other state-owned sites (Marksville and Poverty Point), and was thus able to suggest Los Adaes as a suitable candidate. Los Adaes had already seen enough archaeological investigation to establish its historical importance (Gregory et al. 2004), the presence of a wide range of feature and deposit types, and relatively intact condition. Other factors that made Los Adaes a strong candidate were the fort's visually compelling (six-sided, three-bastioned) layout, the existence of two historic maps that could serve as a source of hypotheses about site function and content, and the existence of several artist's conceptions of how the site may have looked during its period of occupation. That visually compelling artwork was available for use by the project and could play an important role in engaging interest in the project by CRM professionals and the general public. McGimsey was familiar with the Louisiana Division of Archaeology's criteria for issuing excavation permits, and indicated that a research proposal involving large scale geophysics and small scale excavations at no cost to the State would likely be favorably received.

4.1.2 Site Location

Los Adaes State Historic Site (16NA16) is located near the small community of Robeline in Natchitoches Parrish, west-central Louisiana (31^{o} 42' N 93^{o} 17' 36" W). Located approximately 12 miles from Northwestern Louisiana State University (NSU), Los Adaes had already been the focus of historical and archaeological investigations by several NSU researchers, including Dr. H. Pete Gregory (Gregory, et al. 2004). The site includes the archaeological remains of a presidio (hereafter called a fort), Catholic mission, and settlement established by the Spanish in 1721, shortly after the appearance of a French trading post in nearby Natchitoches, Louisiana, and abandoned by 1771 (Gregory, et al. 2004). Relatively little was known about the remains of the Mission. It was the fort that that appeared to meet all of the project's requirements for a demonstration site.

The Los Adaes State Historic Site is situated in a somewhat rural residential area, approximately one mile from a well-used parish road. It is shielded from the access road by trees and is typically visited primarily by school groups and those with an interest in local and regional history. The site includes a small museum with exhibits that interpret the site's history and significance, as well as the small staff's offices and support facilities. Electricity, water, a restroom, and adequate parking were also present. The area of the fort was covered in lawn-like grass with widely spaced shade trees, representing a nearly ideal setting for the project's geophysical survey as well as for the NPS class. The only noteworthy obstacles were horizontal wood beams (about one foot in height) arranged to convey the fort's layout to visitors, and the

site staff graciously temporarily removed them prior to the 2009 geophysical survey (the beams were left in place during the 2008 preliminary survey described below).

Figure 4-1. Location of Los Adaes State Historic Site in west-central Louisiana.

4.1.3 SITE MISSION

Los Adaes State Historic Site's current mission is to preserve and interpret for the public its 18th century deposits and history. During the 18th century, the site's military mission was to prevent French intrusions into Spanish territory. A Catholic mission associated with the fort attempted to spread the Christian faith to local Native Americans. Unofficially, Los Adaes was important as a trade center for the Spanish garrison, their families, the French settlement at Natchitoches, and a large, militarily dominant but non-hostile native population (Gregory, et al. 2004).

4.1.4 Relevant Portion of the Site

Archaeological deposits at Los Adaes can be divided into three complexes: the fort, a scatter of multi-cultural domestic structures around the fort, and the mission. Little is known about the mission, most of which is currently too overgrown for geophysical survey. Several of the domestic structures located near the fort have been excavated (Gregory, et al. 2004), but their remains are relatively ephemeral and do not play any significant role in this project.

Remains of the fort are currently the interpretive focus of the state historic site, and were the focus of the project field demonstration. Unless specified otherwise, all subsequent references to Los Adaes pertain only to the fort and immediately surrounding grass-covered area. Figure 4-2 provides an aerial view of the site (taken by NSU archaeologist Dr. Tommy Hailey; the camera faces North). One can see in this photograph the horizontal beans that convey the fort's size and shape. The 6-sided fort measured approximately 100 m across and occupies much of the cleared land. The western-most portion of the fort extends into a wooded area and has not been located (Gregory, et al. 2004). Small areas of close-cut grass separate the fort from the surrounding wooded area on the west and south. A small area of sloping open land is present immediately east of the fort, but the largest open area is located northeast of the fort. The modest building that houses the museum and staff offices and served as the base of operations during the demonstration fieldwork is located immediately southeast of the fort.

Figure 4-2. Aerial photograph of Los Adaes State Historic Site. Horizontal beams show the approximate dimensions of the six-sided fort. The museum and parking area are seen in the lower right corner.

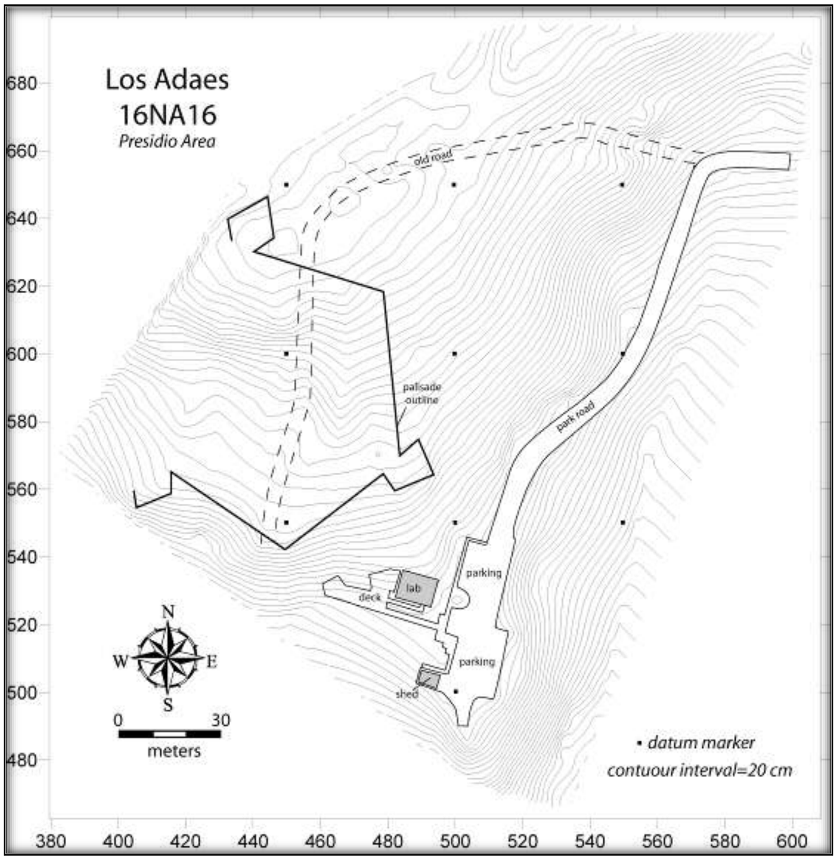


Figure 4-3. LiDAR-based topographic map of Los Adaes.

Figure 4-3 provides a topographic map of that portion of Los Adaes that served as the demonstration site. It can be seen that the fort was located just south of a ridge crest and occupied a reasonably strategic position. Although this is the most detailed available topographic map, it does not convey how the fort's interior consisted of a man-made depression surrounded by low ridges. That aspect of the fort's layout is discussed further in Chapter 5.

4.1.5 SITE HISTORY

Los Adaes (16NA16) is the archaeological site of the capital of the Spanish province of Texas, although today it is located in present-day northwest Louisiana. Named after the Adaes Indians, the site of Los Adaes is defined by a presidio, a mission, settlers' houses, agricultural fields, and roads, and was occupied between 1721 and 1773. Much of the site is now owned by the State of Louisiana and is operated as a state historical site by the Louisiana Office of State Parks. The presidio was called Nuestra Señora del Pilar de los Adaes, and the mission was called San Miguel de Cuellar de los Adaes. Today, historians and archaeologists follow the shorthand observed in 18th century documents and refer to the fort, mission, and settlement as simply Los Adaes (Avery 2011).NEED TO ADD TO REFERENCES

A French post among the Natchitoches Indians, another American Indian group, was only 20 miles to the east of Los Adaes. Presidio Los Adaes was hardly an exemplary military post (one inspection revealed only two operable muskets for 60 soldiers), and the mission had no living converts (the only baptisms of neophytes were in *articulo* mortis, or, at the hour of death). The French were more interested in trading than acquiring territory, and the Caddo Indians viewed the Spanish more as a source for material goods rather than spiritual edification. As a result, Los Adaes functioned more as a trading post and settlement, than a fortification and mission. When Los Adaes was abandoned in 1773 the settlement had a population between 300 to 500 people (Gregory and McCorkle 1981; Avery 1999) (Avery 2011).

The French set the tone of the European intrusion by establishing economic and social relationships with both the Caddo and Spanish. The French practice of unrestricted trade and intermarriage with both the Caddo and Spanish, and the lack of a French missionary effort created a situation where each cultural group could freely adopt or reject traits of the other groups, without fear of reprisals. The Spanish had little choice but to follow the example set by the French, even though the Spanish would not trade firearms or alcohol to the Caddo. Pete Gregory (1973) has described the Spanish, French, and American Indian interaction as a cultural symbiosis whereby three ethnic groups were able to maintain their distinct identities while adopting certain elements of the other groups. This interrelationship is quite clear in the archaeological assemblage from Los Adaes. The large percentage of French and American Indian artifacts recovered from Los Adaes clearly indicates strong economic ties between the Spanish, French and American Indian peoples.

The layout of buildings within the fort is depicted on two historic maps (Figure 4-4). One of these is an architect's plan drawn in 1720. The second map was drawn during a 1767 military inspection conducted shortly before the fort was officially abandoned (some French and Native Americans may have remained at the site after the Spanish garrison and their dependents left). As the demonstration project progressed, questions about which of these maps is most accurate—and reasons for their differences—emerged as one of the primary historical research topics. That topic will be the focus of a manuscript to be submitted to a peer-reviewed professional journal.

4.1.6 Site Operation

Los Adaes State Historic Site was open on a daily basis until shortly before the demonstration fieldwork in 2009. Site visitors were few, particularly during the summer months, and had been declining since the onset of recession. The site managers made the facilities available during the field demonstration, and the site is expected to reopen when economic conditions permit. The site's official closure did not diminish its suitability as the project's demonstration site. On the contrary, it insured that activities associated with the week-long National Park Service's annual introductory course in geophysics were not complicated by school groups or other casual visitors.

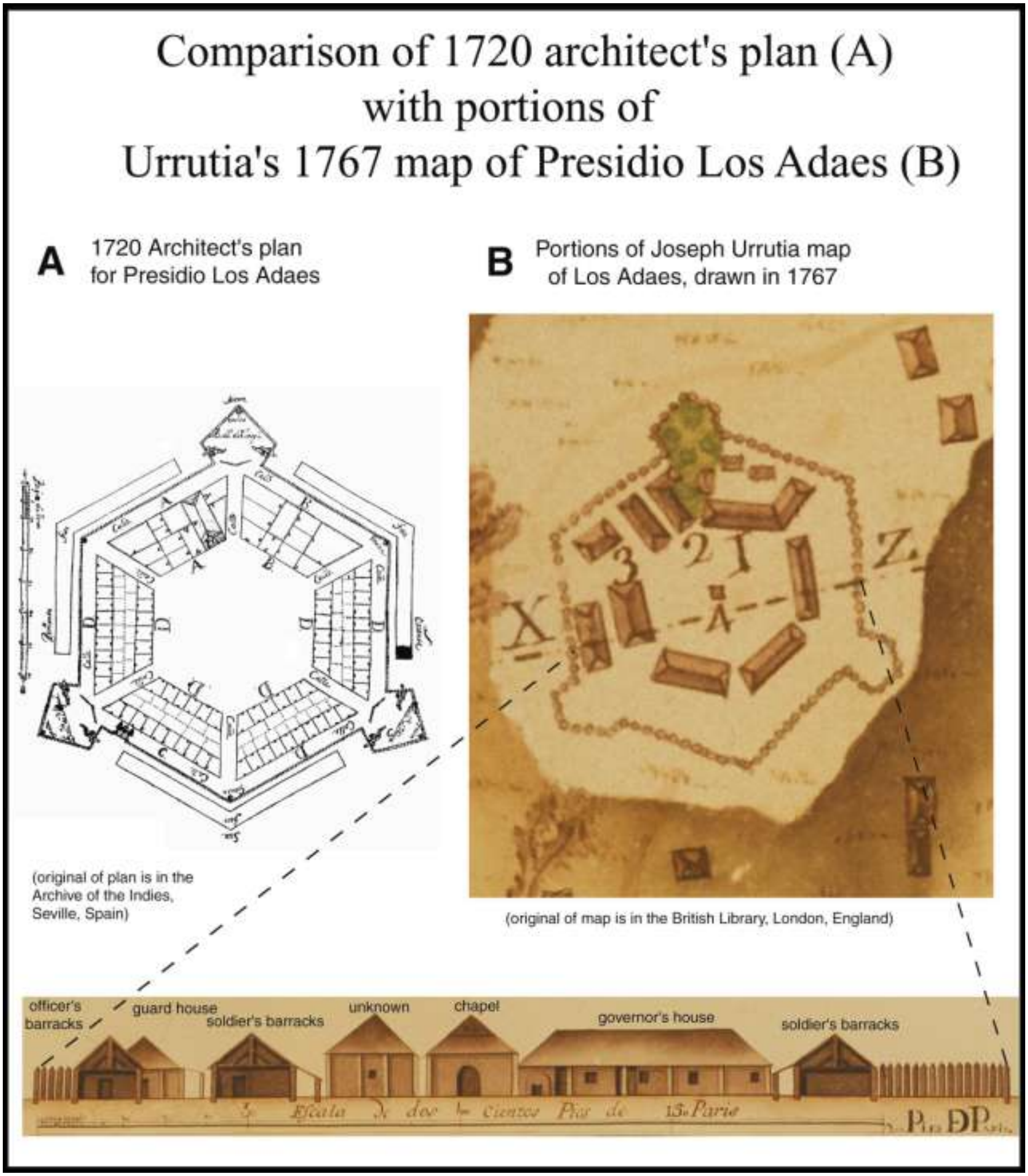


Figure 4-4. Comparison of the two historic maps of Los Adaes (from Avery 2011:21).

4.2 SITE CHARACTERISTICS

4.2.1 SITE CONDITIONS

Climate: Louisiana has a humid subtropical climate. Winters are mild, with the average minimum temperature in January being 36o F and the average maximum being 56.7o F. July and August are the hottest months, with average highs of 93o for July and August, and average lows of 73o and 72o (respectively). Precipitation ranges from a monthly low of 3.39 inches in July to a high of 5.92 inches in December (all values pertain to Natchitoches, LA). These conditions were not a limiting factor for the demonstration project.

Depositional Integrity: Archaeological deposits at Los Adaes are in relatively good condition (the site is listed on the National Register of Historic Places). Despite the previous presence of a late 19th and/or early 20th century house northeast of the fort, the site shows no evidence of a clear plow zone (the site was probably treated as the yard and farm lot rather than a field), and intact archaeological deposits are located immediately below the topsoil. Previous excavations (Figure 4-4) disturbed much of the north and east palisades and the north and southeast bastions (Gregory et al. 2004). Sixty-three 1 by 1 m units were excavated at 12 m intervals along north-south transects spaced at 20 m east-west were excavated in an unsuccessful search to locate the west palisade. Extensive hand excavations were conducted along the east and north palisades and the southeast and north bastions. Perhaps the greatest adverse impact to the site was the construction of a parish road that bisected the site during the 1930s, long before the site was acquired by the state (Figure 4-3). Gregory conducted salvage excavations in the area where that road passed through the Governor's house (Figures 4-4 B and 4-5) (1973; Gregory et al. 2004). More recently, Avery conducted small scale excavations in areas where tree-fall exposed archaeological deposits. Other than that, very little excavation has occurred within the fort.

The factor that caused the greatest concern when we were finalizing our selection of Los Adaes as the demonstration site was the presence of naturally occurring, iron-rich "ironstone". We assumed that material would be highly magnetic and might degrade the quality of magnetic and electromagnetic data. A preliminary survey (discussed in Chapter 5) suggested that the ironstone was restricted to limited portions of the site.

A second issue considered during site selection concerned the results of previous geophysical investigations. In 1995, Avery, Gregory, and Hailey conducted a magnetic survey at the site using a Geometrics Model G Portable Proton Magnetometer (an instrument that is far less sophisticated than those currently in use). Lacking appropriate software, they plotted the raw data by hand and determined that the instrument could detect disturbed areas associated with the fort. Their effort did not, however, provide much information about the usefulness of more sensitive and versatile systems that were available by 2008.

In 1999, Marco Giardino (Stennis Space Center) and George Avery conducted a GPR survey at Los Adaes using a GSSI SIR-2 equipped with a 500 MHz antenna. Data were collected along 73 transects spaced at 1 m intervals. The fosa or ditch outside the palisade, as well as a possible clay cap, was reportedly detected on the south side of the fort (Figure 4-6), but not on the north and east sides. Also detected were anomalies that may have been associated with house floors and a layer of ironstone (Avery 2000). Several profile images of the GPR results were available, but it

is unclear if the data were ever used to generate horizontal time-slice (plan) maps. On balance, the 1999 survey suggested that GPR could detect at least some of the site's features. The results of those two "early" geophysical surveys were not a major factor in our decision to choose Los Adaes as the demonstration site. Those surveys did not provide a great deal of positive information about the usefulness of geophysics at the site, but they provided no indications that the approach would not work there. It was decided to conduct a small-scale, preliminary survey at Los Adaes to provide definitive evidence that the site was amenable to a multi-sensor geophysical approach. Results of the preliminary survey are discussed in Chapter 5.

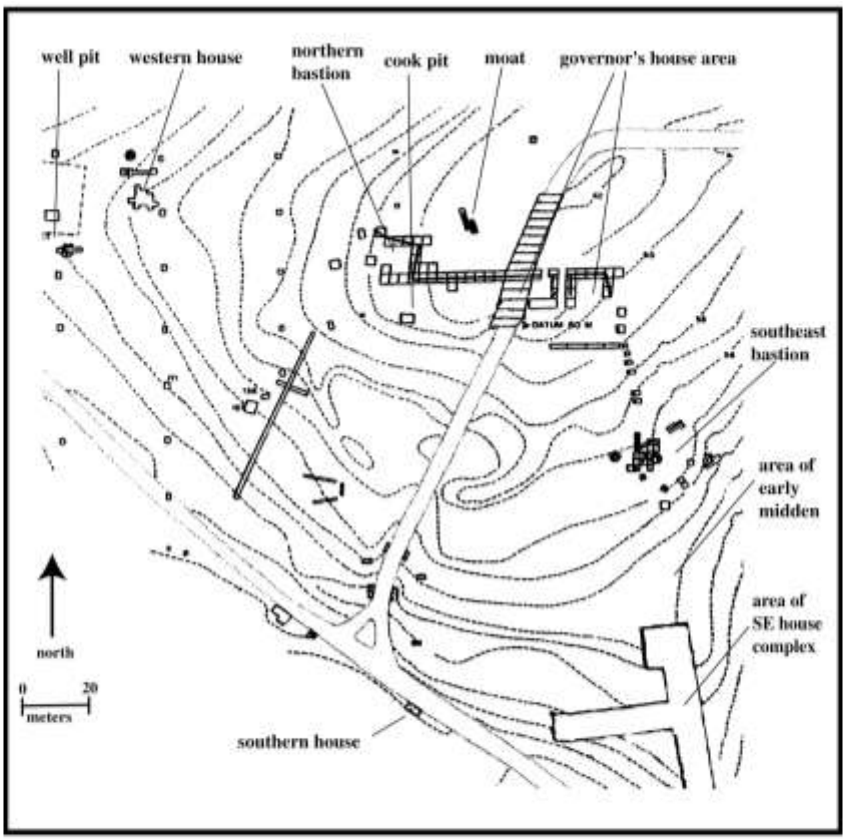


Figure 4-5. Location of previous excavations of the Los Adaes fort.

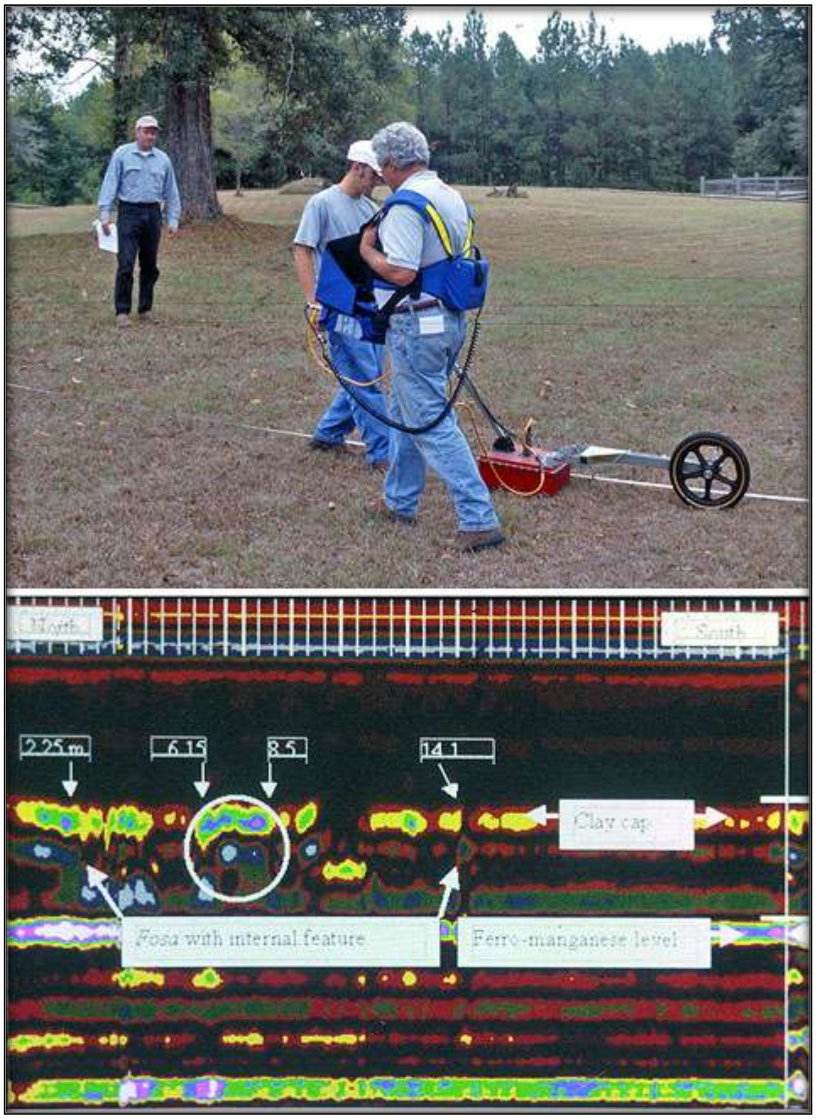


Figure 4-6. GPR survey by Giardino and Avery. (Top) Image of GPR data collection underway; (Bottom) GPR reflection profile showing anomalies interpreted to be the fosa (ditch) and clay cap. (Image source: www.crt.state.la.us). Original Caption: "Results of Ground Penetrating Radar Survey: This slide shows the result of a ground penetrating radar survey transect running across the area of the defensive ditch just outside of the southern wall of the presidio at Los Adaes. Electromagnetic pulses are shot into the ground and a receiver records the reflected pulses. Differences in soil composition will result in different reflection of pulses. The readings suggest a large area of disturbance, which means that this area was dug out and filled in again. It appears that the defensive ditch was dug out and then probably filled in with garbage, just like the excavations of the defensive ditch near the northern wall demonstrated. Dr. Marco Giardino and Dr. Ramona E. Pelletier (Travis) of the John D. Stennis Space Center in Mississippi conducted the ground penetrating radar survey at Los Adaes. (Photo credit: Top photo by Jeff Girard, NSU. Bottom GPR read out generated by Dr. Marco Giardino, John D. Stennis Space Center, Mississippi)."

5.0 TEST DESIGN

This section provides a detailed description of this project's design and testing components. The Project's two main objectives are broken down into several parts each, as described below.

5.1 CONCEPTUAL TEST DESIGN

This project's main objectives are listed below and broken down into the following steps:

1. Project Objective 1 was to create *ArchaeoFusion*, a new user-friendly software that allows individuals with relatively modest levels of expertise and experience to accomplish the data processing required by the integrated multi-sensor approach. (all steps below are described in Section 5.3)
    a. *ArchaeoFusion* Alpha Design
    b. *ArchaeoFusion* Beta Test Design
    c. Ongoing testing and development of *ArchaeoFusion*
2. Project Objective 2 was to demonstrate and validate the cost and performance benefits of the approach and technology infusion tool (*ArchaeoFusion*) to DoD geophysical users, representatives of federal, state, and tribal Historic Preservation offices, federal and state resource managers, and other CRM practitioners. All steps below are described in Section 5.4, unless otherwise noted. Steps b-e were accomplished during the field demonstration at Los Adaes State Historic Site.
    a. Beta test of *ArchaeoFusion*
    b. a multi-sensor survey of a complex archaeological site (Los Adaes State Historic Site, Louisiana)
    c. Processing and integration of the Los Adaes geophysical data using *ArchaeoFusion*
    d. Make predictions about the nature of subsurface features at Los Adaes
    e. Test these predictions with ground-truth excavations. An independent evaluation of those predictions by means of small-scale, carefully targeted excavations
    f. Presentation and dissemination of results (described in Section 5.6)

5.2 BASELINE CHARACTERIZATION AND PREPARATION

5.2.1 PRELIMINARY GEOPHYSICAL SURVEY

A preliminary geophysical survey was conducted at Los Adaes in early September, 2008, by Eileen Ernenwein and Michael Hargrave, assisted by University of Arkansas graduate students Duncan McKinnon and Stephanie Sullivan. The preliminary survey was undertaken to ensure that the site was amenable to geophysical investigation. In preparation for the preliminary survey, we identified and coordinated with the previously mentioned local archaeologists who

had long-established research interests in the site: Dr. Pete Gregory (NSU in Natchitoches), Dr. George Avery (formerly the Los Adaes site archaeologist, and now director of the CRM program at Stephen F. Austin University, TX) had both conducted archaeological excavations at the site, and agreed at that time to serve as consultants for project. Dr. Tommy Hailey and Mr. Jeff Girard (both of NSU) also had a long-term interest in the site and were very supportive of the ESTCP-funded work. Dr. Hailey was an Associate Professor at NSU, directed the university's Cultural Resources Management program, and had served for several years as one of the volunteer instructors at the NPS annual course. His research specialty was aerial remote sensing using a "powered parachute" aircraft. Dr. Hailey arranged for NSU students Suzanne Graham, Dean Barnes, and Ryan Smith to assist us during the preliminary survey by collecting GPS data and assisting in the collection of electrical resistance and GPR data.

The preliminary survey at Los Adaes included use of magnetic gradiometry, electrical resistance, and ground penetrating radar (GPR) (Figure 5-1). The magnetic survey covered an area of 6,000 m^2, the electrical resistance survey covered 2,000 m^2, and 1,200 m^2 were covered by GPR.

Figure 5-1: Preliminary survey of electrical resistivity (left) and GPR (right). Note the horizontal wood beams.

At this stage in the project we did not know whether one of the two historic maps was more accurate, or if they accurately depicted the fort at opposing ends of its roughly 50-year use life. Initially, we simply plotted the magnetic and resistance data onto both maps, and positioned them based on a visual assessment of their best fit. The magnetic gradient data covered a 60 by 100 m (6,000 m^2) rectangular area that included much of the eastern portion of the fort including the southeast bastion, two complete barracks, and a portion of the Governor's House as indicated on the 1767 map.

Visually, the most prominent aspect of the magnetic data is the presence of a wide band of negative values (plotted as white) associated with the iron rebar used to hold the horizontal wood beams in place (Figure 5-2). The entire area surrounding the beams is white because that is the color associated with missing data. The extreme positive and negative values in that area were initially simply removed. This made it possible to remove striping in the raw data without

creating visual defects in the vicinity of very strong values (the preliminary survey was conducted and the data process using Geoplot because *ArchaeoFusion* was not yet fully functional). We recognized that the rebar would need to be removed when we returned for the primary geophysical survey, but the site managers assured us that could be done.

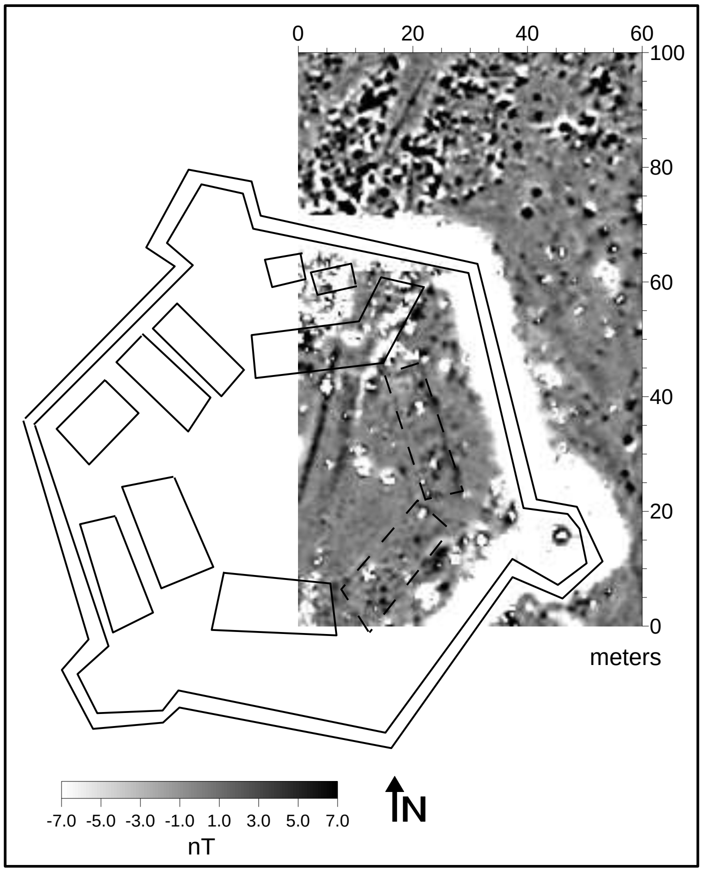


Figure 5-2: Magnetic gradient data collected during the preliminary survey atop outline of the 1767 map. The massive white anomaly is caused by iron rebar used to hold the horizontal wood beams in place.

A second noteworthy characteristic of the preliminary survey's magnetic data was the presence of a dense scatter of relatively small positive and negative anomalies northeast of the North Bastion (Figure 5-2). This scatter extended into the fort, but there most of them were removed during data processing (and plotted as missing data). The 1930s road clearly cut through the anomaly scatter, indicating that they were restricted to a relatively shallow depth (the road bed in that portion of the fort was not as deeply entrenched as it was further south). At the time we proposed three possible explanations for the anomaly scatter: 1) A concentration of nails, bricks, and other magnetic artifacts associated with a 19th century occupation (as noted, a late 19th to early 20th century house was present southeast of the anomaly scatter); 2) An area of 18th century midden; (that explanation seemed unlikely, since iron objects would likely not have been abundant enough to account for the many anomalies. 3) A concentration of the iron-rich

sandstone described by previous excavators. The third explanation was viewed as the most likely and proved to be the correct one. Importantly, the fact that the ironstone was sparse or absent across a good portion of the fort's interior removed our final concerns about selecting Los Adaes as the project's demonstration site.

Another important result of the preliminary survey was the detection of linear magnetic anomalies—some of them strongly positive and others weakly negative—co-occurring with architectural features shown on the 1720 plan. These suggested that architectural features would be manifest as both relatively high and relatively low contrast anomalies, and would thus contribute to the site's ability to provide a good test of *ArchaeoFusion*'s capabilities.

The resistance survey covered five 20 by 20 m squares (2,000 m^2) arranged to include the southeast bastion, portions of the east palisade and the adjacent ditch, two of the barracks structures inside the fort, and a portion of the 1930s road (Figure 5-3). The palisade and bastion had been extensively excavated (Gregory et al. 2004), but the relatively high and low amplitude anomalies nevertheless corresponded to architectural features indicated by the 1720 plan. The resistance data also indicated the presence of the exterior ditch and internal barracks structures. The structure floors appeared to be manifest by low resistance, possibly indicating that they extended into relatively moist clayey soils. Large but discrete high amplitude anomalies were interpreted as coarser, better drained deposits, possibly midden. While it would have been premature to offer more detailed interpretations, the overall patterning of high and low amplitude resistance anomalies clearly seemed to be correlated with the expected architectural components.

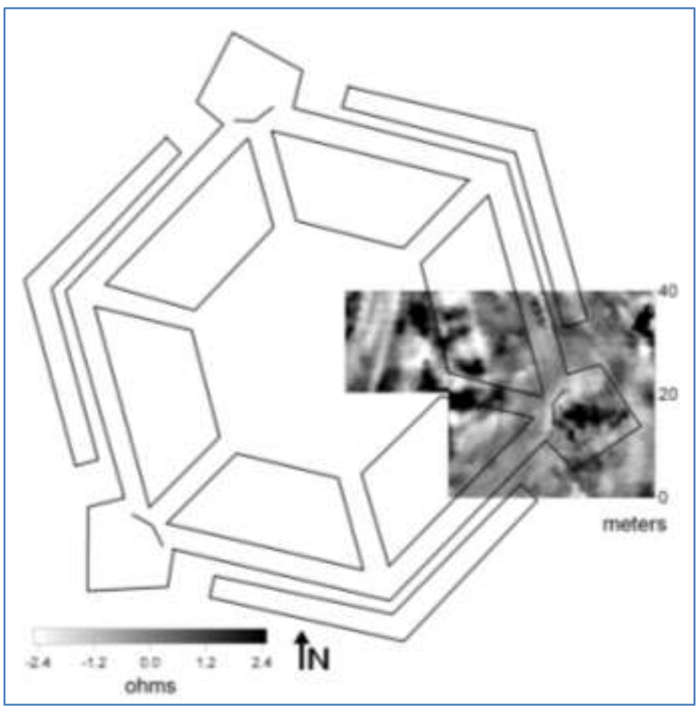


Figure 5-3: Electrical resistance data collected during the preliminary survey atop outline of 1720 architect's plan.

In comparison to the resistance and magnetic data, results of the GPR survey were disappointing. Discrete anomalies were present but were less obviously correlated with architectural features shown in the historic maps. We did not view this as a reason to reject Los Adaes as the demonstration site. GPR data are strongly influenced by soil moisture, and we viewed that as one possible explanation for the disappointing results. Ultimately, it is often the case that some geophysical techniques yield far more useful results than others at particular sites. It is sometimes difficult to predict which techniques will be most effective, and that was, of course, the reason for conducting the preliminary survey.

On balance, the preliminary electrical resistance and magnetic gradiometry surveys revealed anomalies that were clearly associated with the fort's architectural remains, and indicated that clutter associated with naturally occurring ironstone was not present in a large portion of the fort's interior. GPR results were disappointing but we hoped they could be improved by collecting data during an interval of lower soil moisture, and perhaps by using a different antenna. Results of the preliminary survey led us to select Los Adaes as the project demonstration site.

5.2.2 SITE PREPARATION

Activities needed to prepare the site for various stages of the field demonstration included 1) establishing a metric grid, and 2) removing the horizontal beams and rebar.

Grid

An electronic distance measurement (EDM) "total station" instrument was used at the site on a number of occasions to establish the site grid needed to maintain horizontal control of geophysical data and to record the locations of excavation units, features, and artifacts. A grid comprised of 15 20x20 m squares was established on the first day of the preliminary geophysical survey. Corners were marked using wood stakes and plastic pin flags. The stakes were removed at the end of that survey. Their location relative to several of the site's permanent datum markers was recorded using both the EDM and a hand held GPS unit.

The preliminary grid was reestablished and expanded on the first day of the primary geophysical survey (11 May 2009). A total of 21.5 20x20 m squares was established using an EDM. Grid coordinates were written on the stakes, and individual grids were designated by the coordinates of the SW corner. The grid covered all but the fort's western palisade and southwestern bastion as shown on the 1767 map. Those portions of the fort could not be included in the grid (or the geophysical surveys) because of dense trees.

During the NPS class, Hargrave conducted additional magnetic gradient data in the open area NE of the project's grid. This was done on several occasions when the NPS class was covering topics taught by other instructors that did not involve discussion of the integrated multi-sensor approach or *ArchaeoFusion*. This additional data collection was done to achieve more complete coverage of the areas immediately outside the fort. A number of domestic structures were shown in that area on the 1767 map and it was thought that their inclusion in the project's geophysical data would be of interest to many readers of planned journal articles. Working alone, it was not

possible to use the EDM. Hargrave used tapes to establish the additional grids and the locations of their corners were recorded using the EDM during times when the NPS students and instructors were present to help.

At the conclusion of the NPS class all of the wood stakes marking the grid corners were removed (their locations relative to the site's permanent datum markers had already been recorded).

Horizontal Beams

The horizontal beams that outline the approximate shape of the 18th century fort are held in place by metal rebar. The beams prevented unimpeded movement of the geophysical sensors (particularly the GPR antenna) across the ground surface, and the iron rebar was associated with very strong magnetic values that, in the preliminary survey, precluded detection of anomalies associated with the fort's actual walls. The site managers removed the rebar and wood beams on the first day of geophysical data collection the week preceding the NPS class. Approximately four people removed the beams and rebar and stacked them around the site perimeter where they would not influence the magnetic instruments. Because the beams and iron had been in place for a number of years, no vegetation was present within their footprint. Removal of the rebar left holes that were less than 1 inch in diameter and a foot or more in depth. Discoloration from rust was visible in many holes, and we anticipated that the footprint of the beams and rebar would be at least faintly discernible in data from most or all of the sensors. We were correct in our assumption that this would not be a problem for data interpretation.

Locating test units

When the ground truthing work began, Jeff Girard used an EDM to establish two corners of each of the 1x1 m units selected for excavation. The other two corners of each unit were established using tapes. Girard visited the site nearly every day to establish the locations of several units that were not among the 18 initially chosen, and to record data on depths of excavation, and the locations of particular features and artifacts of special interest.

Avery made other minor preparations for ground truthing. Two highly experienced excavators were hired, hand tools were brought to the site, as well as hoses with high-pressure nozzles like those used by homeowners, and 25 or more large plastic buckets to hold excavated soil prior to water screening. Water screening was done adjacent to a deck that protruded off the museum building. The silt collected below the deck.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY AND METHODOLOGY COMPONENTS

This project includes two technology components: the *ArchaeoFusion* software and several geophysical instruments used during the preliminary and full surveys.

5.3.1 *ARCHAEOFUSION* ALPHA DESIGN

The *ArchaeoFusion* development team (Cothren, Johnston, and Ernenwein) employed a combination of two general models of software development:

- The Spiral Life Cycle Model is a sophisticated life cycle model that focuses on early identification and reduction of project risks. A spiral project starts on a small scale and explores risks, makes a plan to handle the risks, and then decides whether to take the next step of the project--to do the next iteration of the spiral. It derives its rapid development benefit not from an increase in project speed, but from continuously reducing the project's risk level--which has an effect on the time required to deliver it. Success at using the Spiral Lifecycle Model depends on conscientious, attentive, and knowledgeable management. It has been used on many kinds of projects, and its risk-reduction focus is always beneficial.

- The Daily Build and Smoke Test is a process in which a software product is completely built every day and then put through a series of tests to verify its basic operations. This is a construction-stage process, and it can be initiated even when projects are already underway. The process produces its savings by reducing the likelihood of several common time-consuming risks--unsuccessful integration, low quality and poor progress visibility. The process provides critical control for projects in recovery mode. Its success depends on developers taking the process seriously and on well-designed smoke tests. The Daily Build and Smoke Test can be used effectively on projects of virtually any size and complexity.

During the early phases of testing we employed the Spiral Method until the fundamental functionality and interface design was fixed. As the software became more developed and required more careful integration we moved to the Smoke Test Method. For example, early in the design phase various implementations of the operation stack were tested (e.g. where they were placed in the interface, how did the user input values, and how should the input and output of the operation be shown to the user). Once the design and desired functionality were stable, the Daily Build and Smoke Test method was used to distribute modifications and additions to the development team. Members of the development team would test each operation on a representative set of data from various instruments, and compare the results with other somewhat equivalent software. In the several cases in which no equivalent was available (e.g. Automatic Balance, 2D Fourier Filter Design), assessment of functionality was based on expected results. Source code was managed via a source control system while error reports and design questions were posted on a development bulletin board and wiki web-page.

From the development team's point of view, there are three functional pieces of *ArchaeoFusion*: 1) Java-based data import and assembly, 2) Matlab-based operations, and 3) Java-based user interface development. During development, each of these pieces underwent a separate internal QA/QC process.

1. **Import and assemble data from multiple instruments**. A representative set of data collected from all instruments to be supported by *ArchaeoFusion* were assembled. If an instrument had multiple collection modes, then data collected from each mode was included in the representative set. As new import functions were developed, applicable data sets were imported into the *ArchaeoFusion* format, assembled into a survey using the imported metadata and user input and compared to surveys imported user comparable software. Comparisons were not just visual, but consisted of actual comparisons of data

type and values.

2. **Matlab based operations**. The first state of QA/QC consisted of a unit test framework to test basic functionality (see http://blogs.mathworks.com/steve/2009/02/03/mtest-a-unit-test-harness-for-matlab-code/ for more details on the framework we used). This framework was built to automatically run all Matlab-based operations many times, each time with a different set of inputs. File names and line numbers at which errors were found were recorded in an output file along with various numeric, tabular and image output from each operation. The full file was examined for run-time errors, run-time warnings and inconsistent output. If none were found, the unit test for all functions was passed. Passing this unit test ensured the code was consistent and produced "expected" results, however these results still needed to be verified as correct and were compared to other software when similar functionality was provided or by close examination for useful analytical value. A copy of the unit test framework will be made available to ESTCP as part of the source code delivery.

3. **User Interface development**. All user interface functionality was tested by use cases designed by the development team. Projects containing a variety of data types (see Beta Test Report for examples used in the beta test) were shared by the developers and used to discuss and verify modifications to the user interface. While no formal testing procedure was in place for this portion of the code, working and re-working these shared projects identified programming errors that needed to be discussed as well as issues related to interface design.

5.3.2 *ARCHAEOFUSION* BETA TEST DESIGN

Beta Test Environment

The Geomatics II teaching lab (Figure 5-4) is located in the J.B. Hunt Transport (JBHT) Services Inc. Center for Academic Excellence on the second floor near the North end of the building in room 228. This spacious 958 square foot teaching area also functions as a working lab for students enrolled in classes, who are granted access via their student card ID using card readers for unlimited 24 hour access.

At the time of the *ArchaeoFusion* beta test, the **Geomatics II** lab featured 16 high-end Windows XP/64 with dual monitors (one CRT, one LCD) to support stereo photogrammetric, visualization and other high end applications. Each is a quad-core system with 8GB memory. Each CAST teaching lab in JBHT features four Samsung 400PX premium commercial grade monitors featuring high-performance 39.6" dual-input analog/digital LCD displays and DNIe (Digital Natural Image engine) – exclusive image compensation algorithm for brighter and clearer images and text. These displays along with the projection overhead can used to display media, the instructors PC, a student PC, etc. aiding in collaborative education.

Figure 5-4. Geomatics II classroom in the J.B. Hunt Center for Academic Excellence Building. Each student has access to one of the dual monitor workstations. The instructor is able to guide the test via an instructor workstation and 5 projectors (1 overhead and 4 LCD monitors in the corners of the classroom).

Participants

Beta test participants included four Army users and four University of Arkansas Students (see Appendix G). Detailed experience levels were based on the individual's answers to the following questions (from the Tutorial 1 Comment sheets):

1. What types of geophysical methods (magnetometry, GPR, EM, etc.) and instruments (Geoscan, Bartington, GSSI, etc.) are you familiar with?
2. What software do you typically use to process your geophysical data?
3. How long have you been using geophysical methods?

5.3.3 ONGOING TESTING AND DEVELOPMENT OF *ARCHAEOFUSION*

ArchaeoFusion has been in a continuous state of evaluation and development since the beta test was conducted, and development will continue even after the project is completed in order to keep pace with new developments and needs in the archaeological geophysics arena.

5.3.4 GEOPHYSICAL EQUIPMENT

The **Bartington Grad601-2** (Figure 5-5) is a vertical component dual sensor fluxgate gradiometer with data logger and two cylindrical sensor assemblies for use in geophysics and archaeology. Each sensor tube contains two fluxgate magnetometers with a one meter vertical

separation. As a magnetic gradiometer, this instrument is sensitive to very slight fluctuations in the Earth's magnetic field as a result of objects buried in the shallow subsurface and surface variations. The on-board data logger records measurements collected during a survey and allows for gradient maps to be prepared of a study area.

Figure 5-5. Bartington Grad601-2 magnetometer.

This instrument is designed for archaeological prospection and allows geophysical surveys to be completed rapidly. The large non-volatile flash memory and fast downloading of data offer improved survey efficiency. The Grad601 has a linear range of 100nT with a resolution of 0.1nT and a range of 1000nT with a resolution of 1nT. A compressed response is provided to 30,000nT. This instrument operates either in survey mode, where data is recorded while covering an area in parallel or zigzag paths, or in a scanning mode where it is used as a search tool with an audible output without data logging.

The **GSSI SIR-3000 Ground Penetrating Radar** unit (Figure 5-2) is a lightweight GPR acquisition system manufactured by Geophysical Survey Systems, Inc. This single-channel portable interface device is designed for use by a single operator and allows for field data to be collected, visualized, and stored for later download. The SIR-3000 is compatible with all GSSI antennas for survey flexibility. Depth prospection varies based on antenna frequency and substrate, but typical investigations range from 0.5 - 3 meters in depth.

The **Geonics Ltd. EM-38MK2** (Figure 5-6) is a compact electromagnetic induction meter that simultaneously provides measurement of both the quad-phase (conductivity) and in-phase (magnetic susceptibility) components within two distinct depth ranges. The instrument includes two receiver coils separated by 1 m and 0.5 m from the transmitter, which simultaneously provide data within effective depth ranges of 1.5 m and 0.75 m, respectively.

Figure 5-6. Geonics EM38-MK2 Electromagnetic Induction instrument.

The **Geoscan RM15-D Resistance meter** (Figure 5-2) with PA20 probe array and MPX15 Multiplexer allows rapid survey of archaeological sites using a variety of probe configurations and depth settings. For typical archaeological surveys, including those conducted at Los Adaes, the instrument is set up to collect measurements at .5 m depth in a 3-probe array, thus collecting four rows of data in one passage of the instrument.

5.4 FIELD TESTING

Field testing for this project includes all the steps taken as part of the second project objective. These include (a) a beta test of *ArchaeoFusion*, (b) multisensor data collection, (c) data processing and integration using *ArchaeoFusion*, (d) data interpretation and prediction of archaeological features using *ArchaeoFusion*, and (e) verification of interpretations by ground truth. Steps b-e were accomplished at Los Adaes, the project's demonstration site.

5.4.1 *ARCHAEOFUSION* BETA TEST

The beta test consisted primarily of 3 guided tutorials over the course of 3 days. The tutorials were designed to evaluate the functionality of *ArchaeoFusion*. Tutorial 1 covered the basic functionality of *ArchaeoFusion*, allowing the participants to assess how the software imports, displays, manages, and processes data. Participants learned these functions by importing and processing data from Silver Bluff Plantation (one of the four sites surveyed as part of the SERDP project). Participants were instructed to import resistivity and magnetometry data files and assemble individual tiles (survey subunits) into larger composites called "surveys." Using these data, the participants experimented with the different tools in the viewer, including modes of viewing data in 3D, zooming, and panning. Finally, the participants processed the two datasets and by doing this learned how the operation stack functions. The operations stack is one of the most unique attributes of the *ArchaeoFusion* software, because it allows users to add operations that process the data, but then go back and change parameters, rearrange the order of operations, and add, delete, or simply turn off some operations to see what the outcome will be. Through an iterative process, the user can find the best approach to processing each dataset, and then save

this operation stack. The operation stack is also a valuable communication and teaching tool. The user can save the operation stack and send to another user, who can then see exactly what operations were used to create the final result, and even change some parameters in an attempt to improve the results. The beta test participants were impressed by this method of data processing.

Tutorial 1 was very detailed so that participants could learn the basic functionality of *ArchaeoFusion*. Tutorial 2, however, was less specific (i.e., each processing step was not specified), so that participants could begin to learn the software intuitively based on the fundamental knowledge gained in Tutorial 1. This was easy for many, but not all participants. As a result, some participants raced through this tutorial without problems, while others needed help and additional guidance. Tutorial 2 guided participants through the process of adding new data to an existing survey, and working with electromagnetic (EM) data (magnetic susceptibility and conductivity data types) and ground-penetrating radar (GPR) depth slices as Surfer grid files. Data from Pueblo Escondido (another SERDP site) was used for this tutorial. Through processing these data the participants learned how to use new operations that were not needed for the Silver Bluff resistance and magnetometry data in Tutorial 1.

Tutorial 3 introduced the topics of GPR data processing and data fusion. Several of the participants were not familiar with GPR data processing, and almost no one was knowledgeable about data fusion; (*ArchaeoFusion*'s capability for data fusion is another of its most unique and valuable components). For this reason, the instructors walked participants through the steps rather than have them do it on their own by following written instructions. Participants were first shown how raw GPR profiles are brought into the GPR processing wizard, processed, and then assembled into 3D cube files. The cube files were then sliced and assembled into composite images ("surveys") and added to *ArchaeoFusion* just as all other data types are added (as 2D raster images). Next, a variety of data fusion methods were demonstrated including principal components analysis, color composites, mathematical operations, cluster analysis, and Boolean logic operations. The participants were impressed by these functions.

Throughout each tutorial, the participants were provided on-line forms to score and comment on the software. The forms themselves were made available through Google Documents so that the participants always had access to the saved documents. Participants could score and comment during and immediately after a sections of the tutorial (there were several breaks built into each tutorial at which the participants were asked to complete the form), but also at the end of the daily sessions in their hotel rooms if desired. The development team also had read-only access to these forms so that we could more efficiently compile and summarize the results of the individual participants. These forms are still available online at www.docs.google.com (userid: *archaeobeta*, password: *betabeta*). Most of the participants used these forms (which were always available on the second monitor) to comment on functionality or report problems as they occurred.

In addition to the forms provided for rating specific functionality of *ArchaeoFusion*, the participants were also asked to complete an Overall Assessment. This assessment was more qualitative and attempted to assess the participants' views concerning the current Archaeological Geophysics practice and how *ArchaeoFusion* will affect current practices.

***ArchaeoFusion* Function Specific Ratings**: Results from the various on-line forms provided to the test participants are summarized in this section. Each of the three tutorials was rated

separately. Student rating tend to be sporadic because their class schedules prevented them from being present during the entire test.

Ratings Keys: Participants were asked to provide numerical ratings for specific sets of procedures in *ArchaeoFusion* using the following rating system.

Ease of Use: How easy is this tool to use?
1 = not at all easy to use or does not work
2 = difficult to use
3 = average ease
4 = fairly easy to use
5 = very easy to use

Accuracy: How well does this tool perform the function for which it was designed?
1 = does not function
2 = functions, but results are faulty (it appears the tool is malfunctioning)
3 = performs the task for which it was designed, with average results
4 = functions well, with good results
5 = works well with impressive results

Effectiveness: How effective is this for producing a good final product?
1 = useless/no benefit
2 = not necessary, but might be applicable in some circumstances
3 = effective, with moderate results
4 = effective, with good results
5 = very effective, produces high quality results

Test Results

The *ArchaeoFusion* Beta Test consisted primarily of three tutorials. Tutorial 1 covered *ArchaeoFusion's* basic design and functionality. Mean scores for ease of use, accuracy, and effectiveness ranged between 4 and 4.7 (on a scale of 1-5, with 5 indicating the highest rating), all of which could be characterized as "good". In short, the beta test team were very impressed by *ArchaeoFusion* and strongly approved of the design and functionality. In Tutorial 2, most of the beta testers continued to assign scores of 4, while a few 3’s as well as 5’s were recorded. One of the Army users (Beta Test Participant 4) assigned scores lower than all the other testers in Tutorial 2: all 3’s for section 1, and 2’s for the other sections (2 means the software functions, but results are faulty). Yet, in his written comments he explained that the ratings are due to “bugs”, and he offered detailed descriptions of the problems and what needs to be done to fix them. These comments were extremely useful, and all of the “bugs” he described were fixed shortly after the beta test.

Tutorial 3 encompassed data fusion and GPR data processing. Given the lack of experience of most users in the group with both of these, and the fact that the GPR wizard was the newest addition to *ArchaeoFusion* (and therefore the least thoroughly tested and “de-bugged”), these were demonstrated to the users. Overall the users were impressed with both of these components and approved of the development team's plans for finalizing the GPR processing component.

Unfortunately none of the user's took the time to rate this tutorial as they did with the previous tutorials. Comments made during the group's discussion following the demonstration were recorded, however, and some of these were used to make changes and improvements to *ArchaeoFusion*.

At the end of the beta test, users were given a final multiple choice questionnaire designed to elicit their overall assessment of the current state of archaeological geophysics in North America, and *ArchaeoFusion*. All users agreed that geophysical investigations as part of archaeological studies are currently inadequate (question 1), but that when used, geophysical investigations usually improve the quality of archaeological results (question 3). In addition, all but one test participant (Beta Test Participant 4) agreed that appropriate levels of geophysical investigations as part of archaeological studies usually reduce costs and save time (question 2). Beta Test Participant 4 believes that geophysical investigations usually add costs and time, and added the following comment after his answer to question 2: "because their use has not been incorporated into proper design planning". Finally, three of the four users agreed that in the next ten years, geophysical investigations in the US will come to be a recommended but not required part of most archaeological studies by SHPOs and other review groups. Beta Test Participant 4 believes that geophysical investigations in the US will come to be a required part of most archaeological studies by SHPOs and other review groups. Overall, these answers agree with the basic premise of this ESTCP project: that archaeological geophysics, when used appropriately, can improve the quality of results, reduce costs and save time, but currently they are underused and inadequate. In addition, the use of geophysics in archaeology is growing and will come to be recommended if not required by SHPOs and other review groups.

One goal of this ESTCP project is to assemble single, user-friendly software that will serve as an effective medium for infusing the integrated, multisensor geophysical approach into wide use. Questions 5-20 of the final questionnaire were designed to assess the users' perception of *ArchaeoFusion*'s potential to meet this goal. Users were asked to assess the software for three types of users: beginner, intermediate, and expert user. Most users agreed that the software is very effective for beginners because: (1) it provides a geophysics "road map" for the new user (question 5), (2) the interface is easy to use (question 6), (3) there is valuable flexibility in the user interface and the structured analysis approach (question 7), and (4) it is easy to learn and easy to use (compared to other software), and will likely increase the use of geophysics in archaeology (question 8). From the perspective of a novice user, the users agreed or strongly agreed that *ArchaeoFusion* (1) combines ease-of-use with valuable flexibility for archaeological applications (question 9), (2) provides most of the tools needed to process geophysical data (question 10), (3) will reduce the time needed to process geophysical data (question 11), and (4) will enable users to obtain more effective results than previously possible, therefore reducing overall costs and time (question 13). All but one user agreed that the availability of *ArchaeoFusion* will increase the use of geophysics in archaeological investigations (question 14), while one user was neutral. Finally, half of the users agreed that that the software will reduce costs associated with using geophysics for archaeological investigations (question 12), while the other two users were neutral to that notion. Finally, for expert users, nearly all agreed that *ArchaeoFusion* (1) combines ease of use with flexibility for archaeological applications (question 15), (2) provides most of the tools needed for archaeological applications (question 16), (3) will reduce time and costs needed to process data (questions 17-18), (4) will enable users to obtain more effective results than they have before (question 20). For question 19, one user

agreed that the availability of *ArchaeoFusion* will increase the use of geophysics in archaeology, while two remained neutral and one (Beta Test Participant 1) did not answer questions 15-20 because she did not feel qualified to evaluate the software from the perspective of an expert user. In all cases, users that did not agree or strongly agree were neutral, while no users disagreed or strongly disagreed with any of the statements in the questionnaire (see Appendix H, Beta Test Results). The overall assessment from questions 5-20 of the final questionnaire shows that users believe *ArchaeoFusion* has the potential to meet the goal of serving as an effective medium for infusing the integrated, multisensor geophysical approach into wide use.

Based on these findings, *ArchaeoFusion* clearly "passed" the beta test. The testing team was impressed, enthusiastic, and offered many suggestions for improvement that were helpful in ensuing software development. These results showed that *ArchaeoFusion* would be ready for the rigorous field evaluation in 2009.

5.4.2 MULTISENSOR SURVEY AT LOS ADAES STATE HISTORIC SITE, LOUISIANA

Multi-sensor data collection was conducted by Hargrave along with members of the User Group and students and instructors of the NPS course at the demonstration site (Los Adaes State Historic Site, near Robeline, LA) in May 2009. The magnetometry survey was conducted using a Bartington Grad601-2, and covered 13,200 square meters. The electromagnetic Induction survey was conducted using a Geonics EM38MK2, resulting in 7,200 square meters of conductivity and magnetic susceptibility data. Resistivity data was collected using a Geoscan RM15 with MPX multiplexer, covering 8,800 square meters. Finally, a total of 6,800 square meters were surveyed with the GSSI SIR-3000 GPR unit. These survey areas overlap as shown in Figure 5-7.

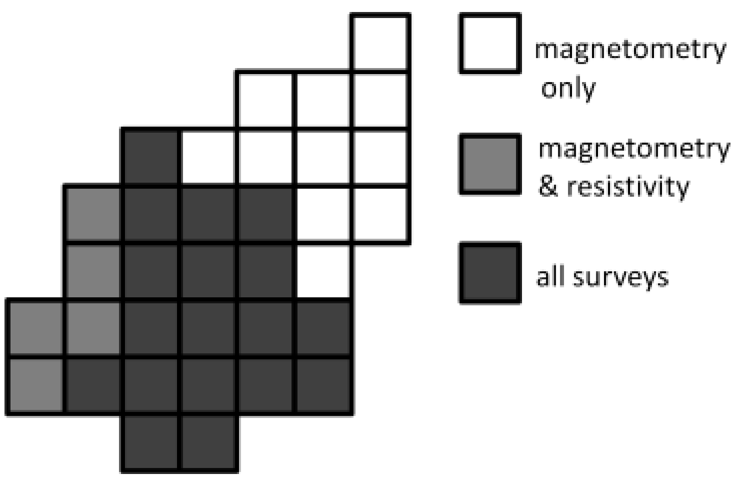


Figure 5-7. Geophysical survey grid at Los Adaes. Squares represent 20 x 20 meter survey blocks.

NPS Remote Sensing Course

The primary public components of the project field demonstration (geophysical data collection and data processing using *ArchaeoFusion*) occurred in conjunction with the 2009 National Park Service's annual 40-hour introductory course in geophysics. The title (but not the focus) of the course changes from year to year. In 2009 it was *Current Archeological Prospection Advances for Non-Destructive Investigations in the 21st Century*. 2009 was the 19th consecutive year of the annual course. The NPS initiated a remote sensing program in 1969 that focused primarily on aerial and satellite sensors (Lyons and Scovill 1978:3; Lyons 1976; Lyons and Ebert 1978, Lyons and Hitchcock 1977; Lyons and Mathien 1980). Bruce Bevan and John Weymouth were important early practitioners of and proponents for ground-based geophysics in the US during the 1970s and 1980s. In 1988, four geophysical practitioners (Clark Davenport, Don Heimmer, John Lindeman, and John Gilmore) demonstrated how the methods could be used at Fort Laramie, and the results were published in a widely accessible, nontechnical handbook (Heimmer et al 1988). By the 1990s, a few NPS archaeologists were conducting their own geophysical investigations. NPS archaeologist Steve De Vore arranged for another geophysical demonstration to be held in Colorado in 1990. The NPS held its first own geophysical workshop in 1991, and the course has been held annually since then. The first two workshops were held at Fort Carson's Piñon Canyon Maneuver Site, and the 3rd and 4th at Fort Laramie. Subsequent courses have been held at noteworthy prehistoric and historic sites across the nation, including Fort Federica, Cahokia Mounds, Spiro Mounds, and the Hopewell Culture Center.

The NPS course is funded by student tuition and sponsorship by the host site and/or other agencies. The instructors include some of the most established practitioners in the US, sometimes supplemented by less experienced researchers who have used geophysics at the host site. NPS typically pays for the instructor's travel and lodgings, but their labor is volunteered. Representatives of firms that provide software and geophysical sensors also attend, generally making their products available for hands-on use by the students and instructors. The students typically represent most or all of the professional communities in US archaeology: students, researchers from academic and private sector settings, and CRM practitioners from federal and state agencies, Tribes, and occasionally, serious avocational archaeologists. In an as-of-yet unpublished (draft) history of that course, Dalan and De Vore note that more than 650 individuals attended the class during its first 18 years.

The ESTCP project team recognized that the NPS class represented the single largest, best known, and most influential gathering of current and future geophysical practitioners and sponsors in the US. Hargrave had served as an instructor since 2003, and course coordinator Steve De Vore was immediately receptive to the proposal that the ESTCP project co-sponsor a course to be held at Los Adaes. Other co-sponsoring and cooperating groups were the National Center for Preservation Technology and Training (NCPTT), which is based at NSU, the Louisiana Division of Archaeology (which is the SHPO), NSU, Fort Jessup, and the Los Adaes State Historic Site.

Demonstration Facilities

All in-doors sessions were held in a conference room equipped with excellent audio, video, and computer facilities located at the NCPTT offices on the NSU campus in Natchitoches. Following standard practice, the NPS course participants convened at that facility at ca. 8:00 AM for lectures and discussions, dispersed for lunch at approximately noon, and reassembled at the Los Adaes site at 1:00 PM for sensor demonstrations and hands-on work with the sensors. Drs. Gregory and Avery provided several tours and discussions of the site's history and results of previous excavations. Each day, field demonstrations began with demonstrations of one or several featured techniques. Multiple sensors for each major technique (GPR, magnetic, resistance, magnetic susceptibility, conductivity) were available, and students were free to focus on any or all systems, and to work with one, several, or many of the instructors. Evening sessions focused on data processing, discussion of data collected by the students and instructors at Los Adaes, and broader issues such as the role of geophysics in CRM in the US. Appendices I and J list the 2009 instructors and students. The 2009 course agenda is provided in Appendix K.

During the week, the students, instructors, and invited observers saw and participated in a demonstration of all the major steps in a multi-sensor geophysical survey. They were provided with detailed background information on the site (many relevant articles and monographs in hard copy and on CD are provided to each student, including Gregory et al. 2004), saw demonstrations and acquired hands-on experience with all of the sensors used by the project team, got at least some experience in processing data (some of the most motivated students got extensive experience), saw and discussed the fully processed data collected by the ESTCP team, and discussed many issues related to data collection and interpretation. Many of the students also developed personal relationships with selected instructors, and those relationships will be useful as they encounter field and processing problems in their own surveys, or need advice concerning surveys they will sponsor in the future.

On Thursday morning (May 21), the project team provided a 2-hour overview of the ESTCP project. Hargrave provided a discussion of the ESTCP project's background and schedule (Appendix L). Dr. Jackson Cothren, Director of the University of Arkansas's Center for Advanced Spatial Technologies (CAST) and leader of the project's software development team then demonstrated *ArchaeoFusion's* capabilities. Cothren later provided demonstrations for several individual students and small groups. *ArchaeoFusion* was functional, but not yet completed, and was not available for independent use by the students or instructors.

Throughout the week, impromptu discussions arose concerning *ArchaeoFusion's* capabilities compared to those of other widely used software (Geoplot, Radan, GPR Slice, and ArchaeoSurveyor). Often such discussions were initiated by instructors who were also the developers or commercial distributors for extant and, in some senses "competing" software. Some of their questions focused on how the software would be distributed and how much it would cost. No such decisions had been made at that time, other than that *ArchaeoFusion* would be available at no cost to DoD users. In general, the students seemed to view very positively the prospect of one software package (*ArchaeoFusion*) capable of downloading and processing data from all sensors. Most instructors were intrigued by *ArchaeoFusion's* potential to "fuse" data from various sensors. Most of them had previously grappled with the task of overlaying the results of several techniques, often relying on multiple colors, superimposing contour lines for

one data set atop image maps of a second method, or simply vectorizing (outlining) anomalies. None of the instructors seemed to be frequent users of statistical approaches (e.g., principle components analysis) to data fusion. This probably reflects the fact that, in the 2009 class, no one had a strong background in satellite or high altitude remote sensing where such approaches are more common.

Several individuals were invited to attend a portion of the NPS class and field demonstration (one to two days) in order to get an overview of the project's goals and methods (Appendix M). Mr. Chris McDade (then the IMCOM archaeologist for the northeastern US), Mr. Bryant Celestine, (Historic Preservation Clerk, Alabama-Coushatta Tribe of Texas), and Dr. Chip McGimsey, Ms. Kelley French? and Mr. Dennis Jones from the Louisiana Division of Archaeology attended. Mr. Bobby Gonzalez (NAGPR Coordinator, Caddo Nation of Oklahoma) and Mr. Robert Cast (Historic Preservation Officer, Caddo Nation of Oklahoma) were both invited and expected to attend, but canceled at the last minute. Two other Native American CRM professionals attended as students: Ira Anderson (Ho-Chunk Researcher & Projects Coordinator, Ho-Chunk Nation), and Bill Quackenbush (Tribal Historic Preservation Officer, Ho-Chunk Nation).

5.4.3 PROCESSING AND INTEGRATION OF LOS ADAES GEOPHYSICAL DATA USING *ARCHAEOFUSION*

Data processing and integration were done during the third and fourth quarters of 2009 using *ArchaeoFusion*. Data processing with *ArchaeoFusion* was much more efficient than previous data processing efforts by project team members during the SERDP project (RC-1263). All of the data could be imported into *ArchaeoFusion* without any need for other software programs. The data were also processed and interpreted by a handful of users as part of the *ArchaeoFusion* Evaluation 1, described in Section 6. The following is a description of the processing, integration, and interpretation done by the *ArchaeoFusion* team.

Magnetometry data were imported directly into *ArchaeoFusion* and processed using zero-mean-traverse to remove striping defects, despike to remove data spikes, destagger to fix positional errors of lines due to instrument lag, Fill to fill in small areas of missing data, mean profile filter to further reduce the appearance of stripes, resample and spatial filter to smooth the data for better appearance and readability. Figure 5-8 shows the data before and after these operations were run.

Resistivity data were imported directly into *ArchaeoFusion* and processed using Fill to fill in small areas of missing data, despike to remove data spikes, balance to automatically match tile edges, mean profile filter to remove minor stripe defects, and resample and spatial filter to smooth the final result. The greatest improvement realized while processing these data was the huge amount of time saved by the Balance operation. This operation simultaneously matches the edges of all selected tiles, and worked flawlessly for these data. The Balance operation does not always work this well, but usually saves some time in data processing by reducing the amount of time spend edge-matching individual tiles. All other geophysical data processing software packages only allow edge matching of tiles one at a time.

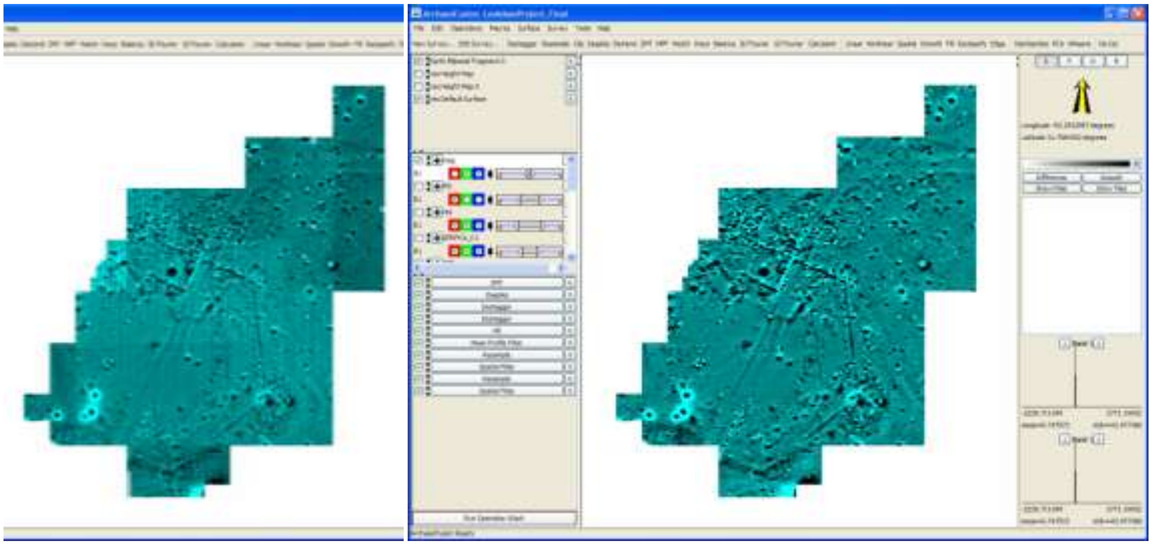


Figure 5-8. Magnetometry survey of Los Adaes shown in *ArchaeoFusion* before (left) and after (right) processing.

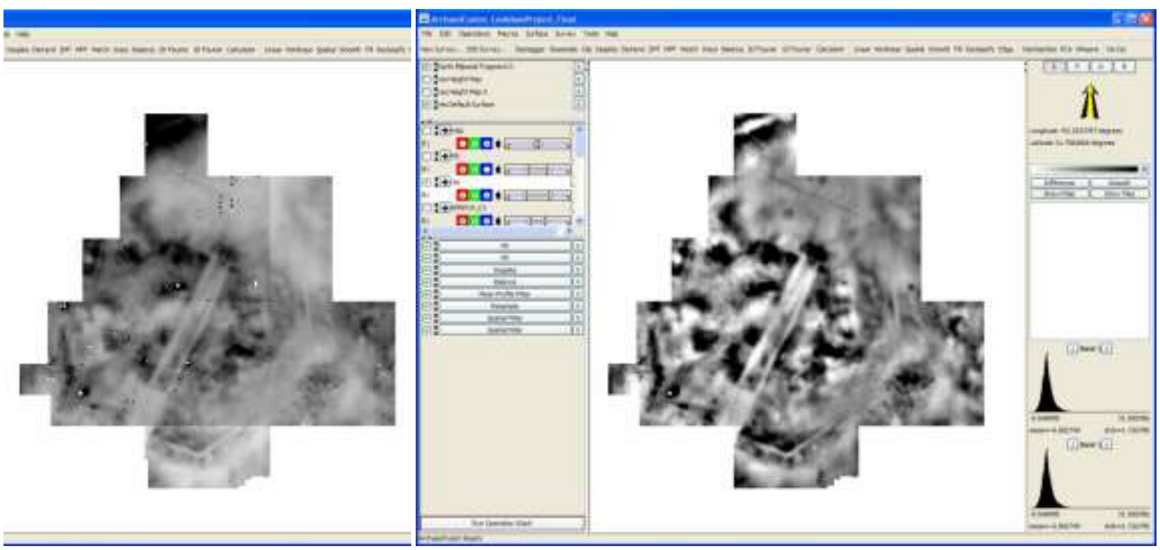


Figure 5-9. Resistivity survey of Los Adaes shown in *ArchaeoFusion* before (left) and after (right) processing.

EMI data were imported directly into *ArchaeoFusion* and first preprocessed using the Tile Editor. This included deleting erroneous lines and removing extra readings that sometimes are recorded at the end of lines before the operator pauses data logging. Prior to *ArchaeoFusion*, these steps had to be done by first removing erroneous lines using Geonics' DAT38 software, and then manually removing extra readings from the ends of lines in Microsoft excel. Doing these operations within *ArchaeoFusion* was much faster and more streamlined, and the dataset could be imported into *ArchaeoFusion* directly. Once the survey was assembled, the different bands of data (0.5 and 1 meter depth versions of conductivity and magnetic susceptibility) were

separated into single-band surveys so they could be processed individually. Conductivity data were very similar to resistivity, and so are not shown here. The magnetic susceptibility from the 1 m coil spacing was an excellent contribution to the project and is shown in Figure 5-10. Processing of the raw data included the Balance operation, which automatically matches the edges of tiles, followed by a series of range match operations to further reduce edge discontinuities between tiles, despike to remove erroneous data spikes, a mean profile filter to reduce stripe artifacts, and resample and spatial filters to smooth the final result.

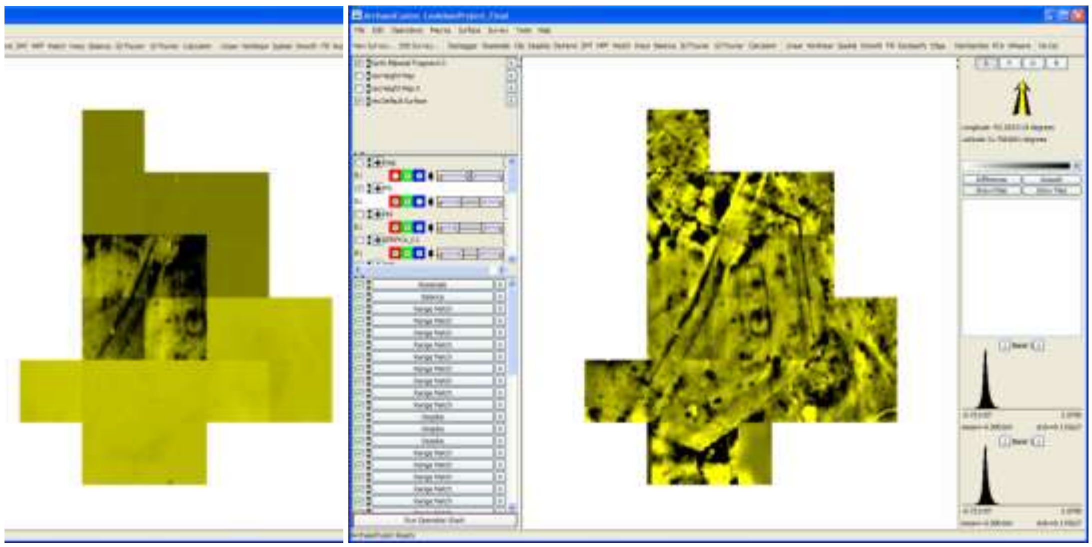


Figure 5-10. Magnetic Susceptibility data from the demonstration site (Los Adaes) before (left) and after (right) processing in *ArchaeoFusion*.

Ground-penetrating radar data were brought into *ArchaeoFusion* directly and each set of reflection profiles was run through the GPR Loader to produce 3D data cubes. These cubes were then sliced and assembled into surveys using the Survey Tool. Since Los Adaes only has one cultural component (was occupied during one time period) all 20 slices showed parts of the same cultural horizon. The slices were therefore fused together using principal components analysis, resulting in one single 2D survey representing 42 percent of the variation from all depth slices. Visual inspection of the principal component results showed that the first component showed the majority of cultural features, while all other components showed noise. This result (principal component 1) was then processed by clipping to reduce the data range and exclude extreme spikes, a series of band calculator and range match operations to match edges, destagger to remove survey defects due to positional errors made by the surveyor, mean profile filter to reduce stripes, and resample and spatial filter to smooth the final result.

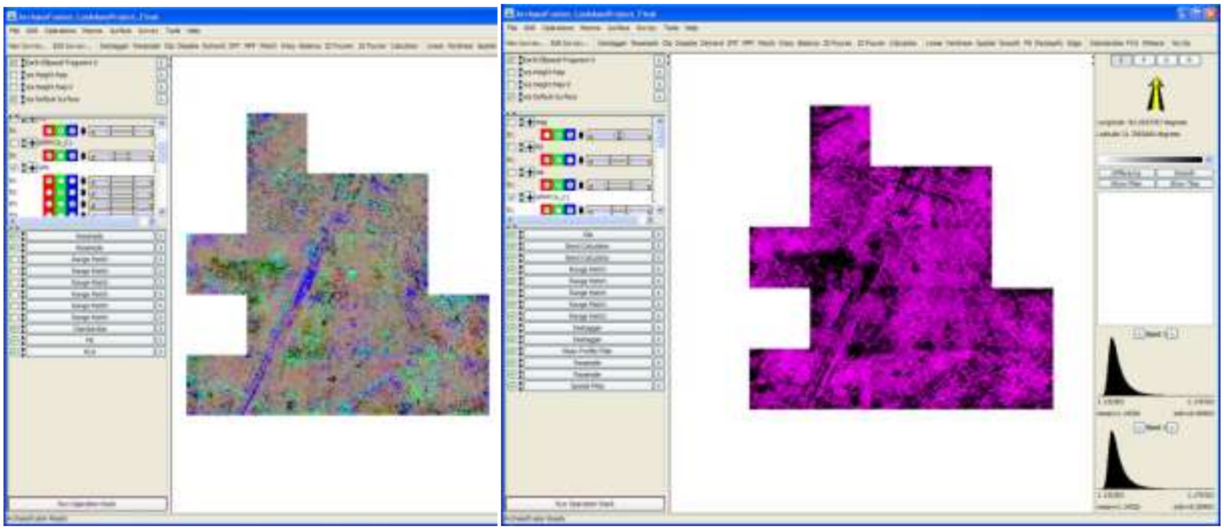


Figure 5-11. Ground-penetrating radar data in *ArchaeoFusion*. The individual depth slices (left, showing stop 3 slices together using red, green, and blue bands) were fused using principal components analysis and then processed as one to produce the result shown (right).

5.4.4 Archaeological Feature Predictions Based on Geophysical Data

Developments in technology have long since led us to assume that modern maps will be reliable and easily understood. Historic maps are less trustworthy. Those found to be reliable can provide a spatial context that dramatically enhances our ability to locate and interpret architectural features. In the best of circumstances, historic maps can contribute to a social or cultural context that may allow insights about the actions, biases, and motivations of those who made and used them. Such contexts can be so valuable that evaluating a map's reliability becomes an important research goal.

Occasionally multiple but seemingly inconsistent maps of a single historic site have survived. The researcher must determine which, if any, is reliable, or whether each map can be useful if their respective functions and conventions can be interpreted, and the apparent discrepancies resolved. This is the situation at Presidio Los Adaes, where two detailed maps survive. An architect's plan drawn in 1720 (Figure 5-12) is highly symmetrical and, in some details, so idealized that one doubts its reliability. A second map (Figure 5-13) was made in 1767 during a military inspection. The detailed depiction of individual structures in plan, and a careful drawing of buildings along a particular axis suggest that this is an accurate depiction shortly before Los Adaes was abandoned.

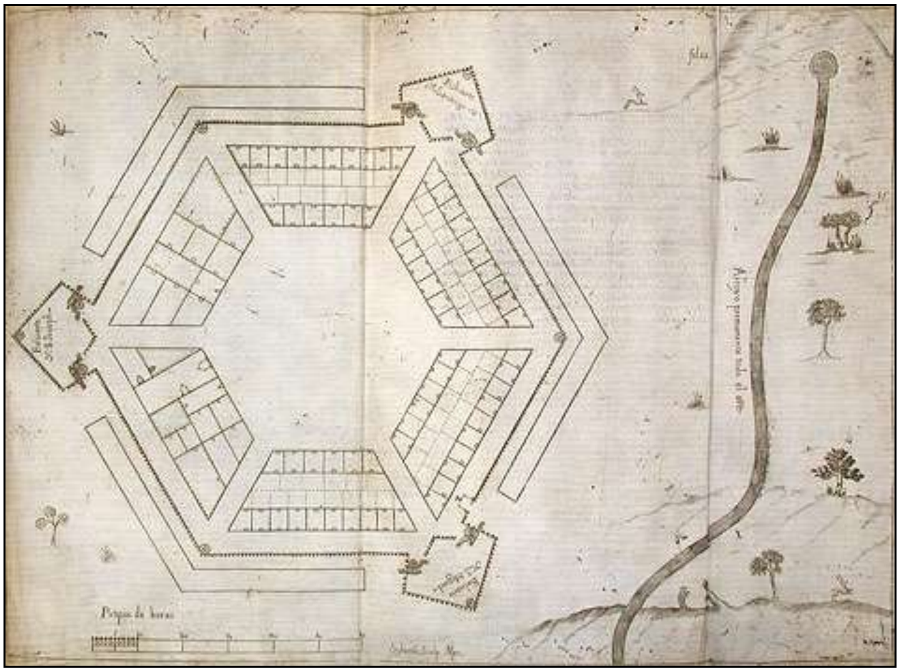


Figure 5-12. Architect's Plan for Presidio Los Adaes, 1720. (source: texasbeyondhistory.net)

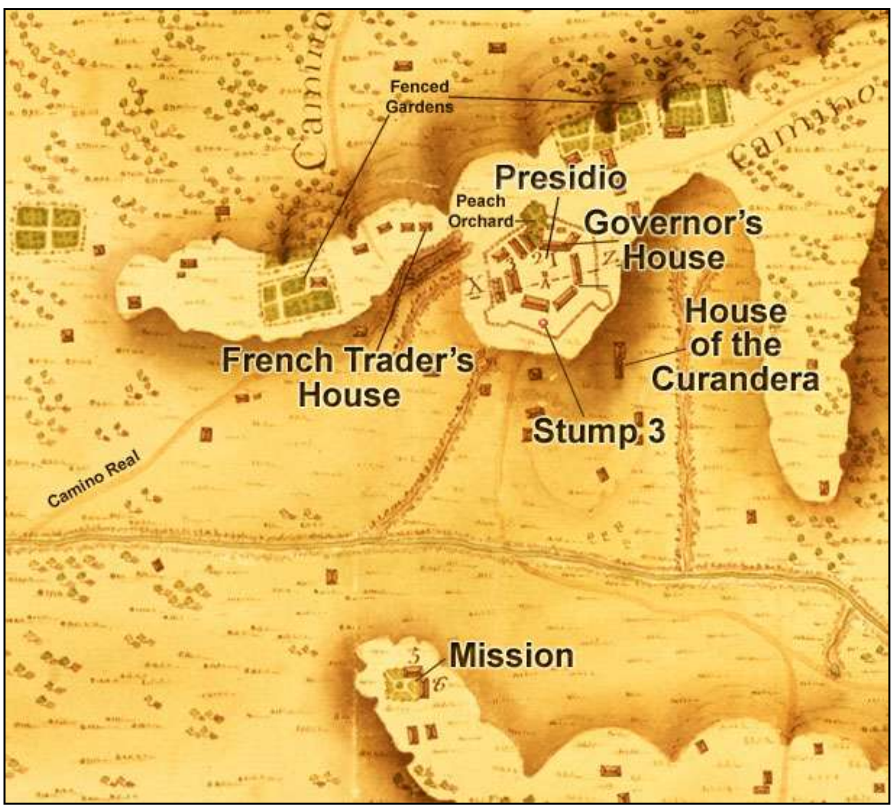


Figure 5-13. Map of Presidio Los Adaes and surrounding area made by Joseph de Urrutia, 1767. (source: Texasbeyondhistory.net)

These maps were a valuable source of information to help interpret the geophysical data, while at the same time the geophysical data were invaluable sources of information with which to evaluate the historic maps. Preliminary interpretations of the geophysical data were therefore made, with the understanding that most questions would remain unanswered until the excavations could be placed to ground truth the interpretations. We therefore present the geophysical data in this section, while details about interpretations are given in the ground truthing section below.

Figures 5-14, 5-15, and 5-16 show the final processed versions of magnetic susceptibility, resistivity, and magnetometry data, respectively. In each figure, the same areas for interpretation are referenced using the letters A-G. Table 5-1 relates selected geophysical anomalies to the 1720 architect’s plan and 1767 map. Magnetometry and magnetic susceptibility reveal the most details about the site, but resistivity data helps support the interpretations.

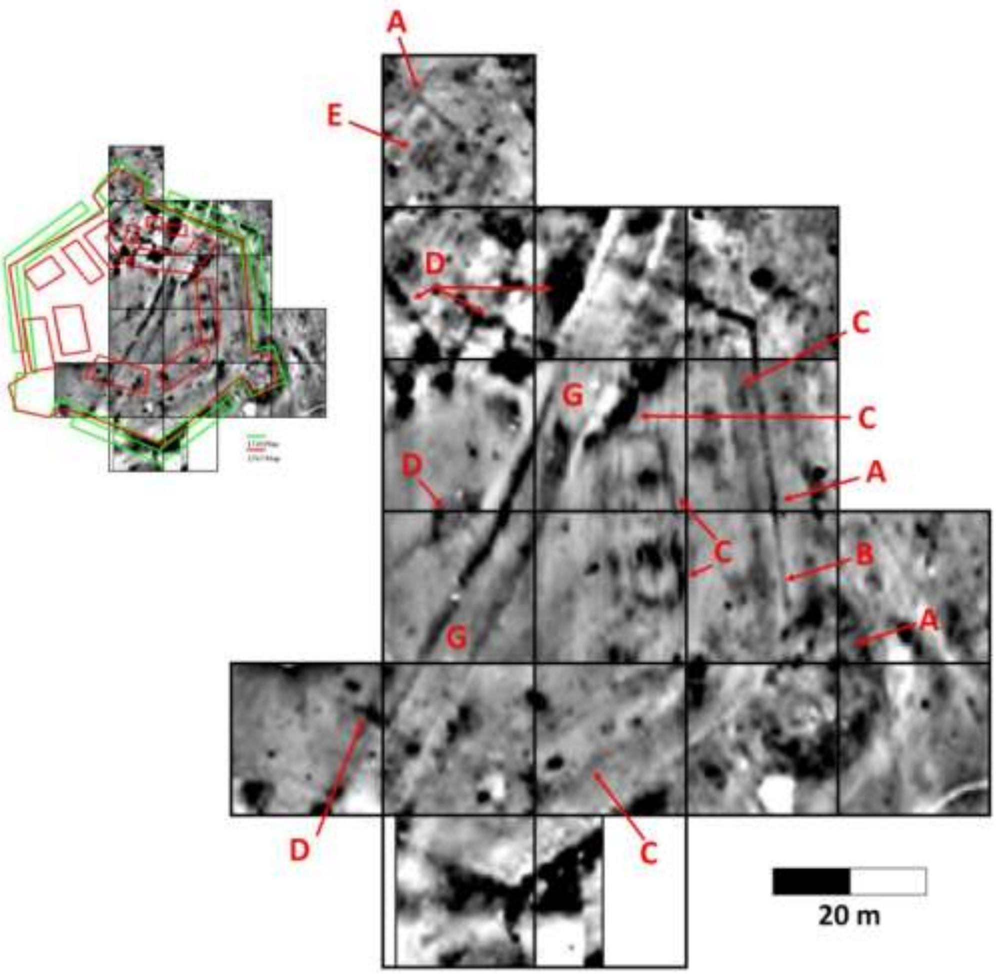


Figure 5-14. Preliminary interpretation of magnetic susceptibility data prior to ground truth excavations. See Table 5-1 for explanations of marked anomalies.

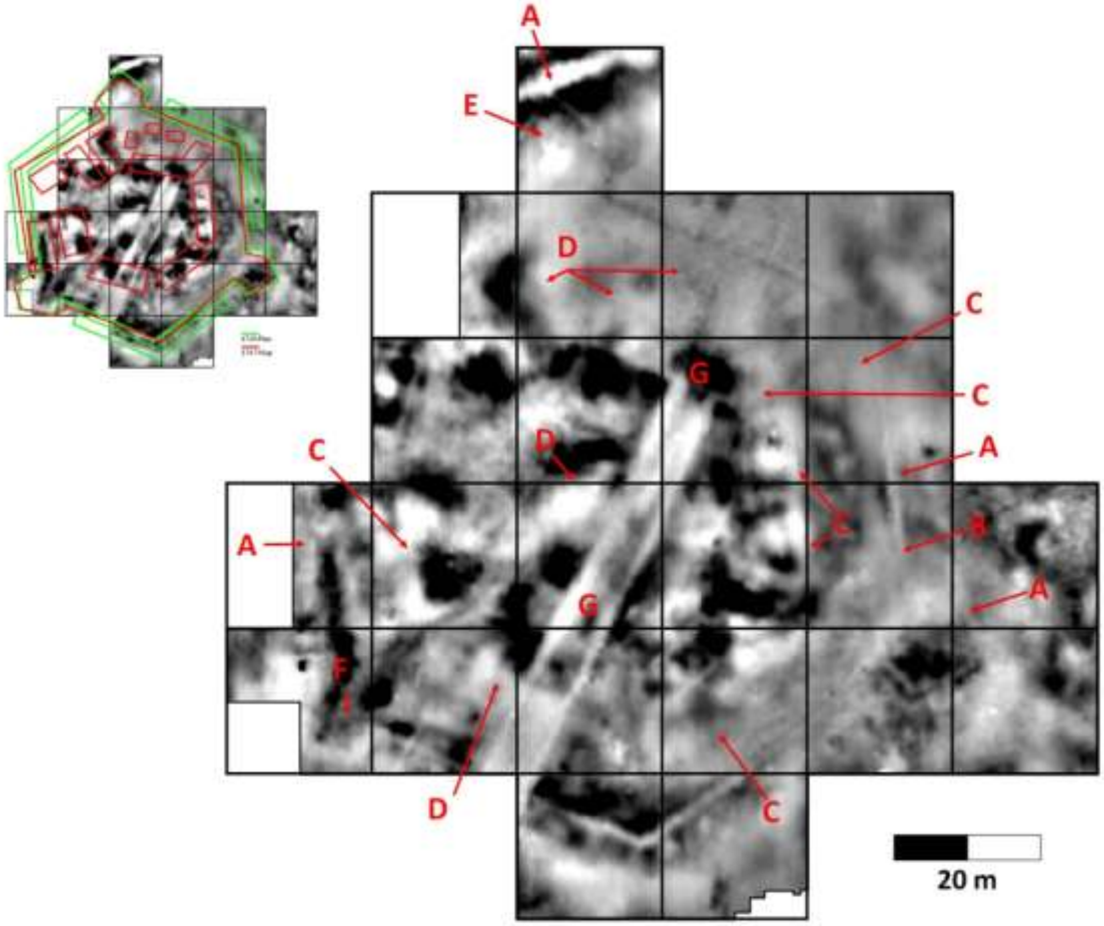


Figure 5-15. Preliminary interpretation of resistivity data prior to ground truth excavations. See Table 5-1 for explanations of marked anomalies.

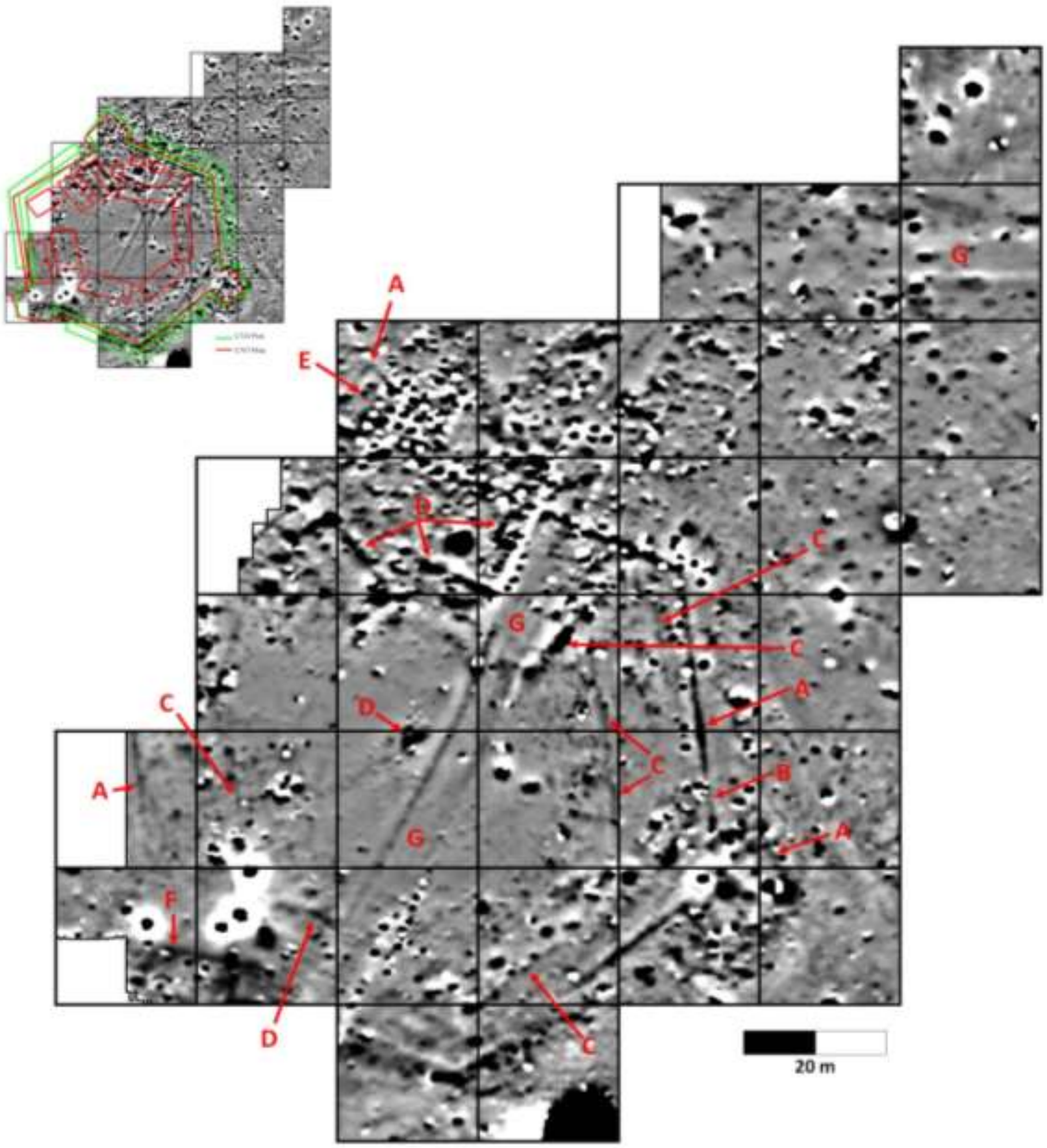


Figure 5-16. Preliminary interpretation of magnetometry data prior to ground truth excavations. See Table 5-1 for explanations of marked anomalies.

Table 5-1. Explanation of anomalies marked in figures 5-14, 5-15, and 5-16.

A	Anomalies that closely align with the Presidio walls in the 1720 plan.
B	Break in the Presidio anomaly in both magnetic datasets that coincides with an entrance to the inside of the fort in the 1720 plan map.
C	Linear anomalies in both magnetic datasets that coincide with structures in the 1720 plan map (see map at left), but do not appear in the 1767 map.
D	Anomalies associated with structures indicated in the 1767 map, including the governor's house, a chapel, a gunpowder house, and soldier's barracks (see drawing in left panel). Their presence at the expected locations supports previous findings that the 1767 map is accurate in many respects.
E	Possible square structure at the northern bastion, indicated by fine lineations in magnetic susceptibility, and alignments of discrete positive and negative anomalies in magnetometry.
F	possible structure near southeast bastion, not indicated on any maps
G	Historic (post-occupation) parish road and ditch that runs through the center of the fort and to the northeast.

Comparisons of the 1720 plan, the 1767 map, and the geophysical data suggested that the 1720 plan was used as a guide for construction, and the palisade detected in magnetometry data closely matched the 1720 plan. The paucity of geophysical anomalies (and thus, features) and artifacts (based on collections along a modern dirt road) indicated the courtyard was maintained as an open, presumably public and somewhat formal area throughout the Presidio's occupation. Existence of the palisade and courtyard imposed many constraints on the arrangement of the Presidio's buildings.

The 1767 map appears to be generally accurate, although its palisade fits the linear magnetic anomaly much less well than the 1720 plan map. Geophysical anomalies and archaeological evidence indicate that paired buildings once existed or were at least partly constructed in the east, southeast, and southwest areas, where only single buildings were present in 1767. Geophysical anomalies associated with buildings that surrounded the courtyard cover a larger area than indicated by the 1767 map. The anomalies fit the 1720 map better than the 1767 map, but are only partially coterminous in each. Buildings that occupied the area west of the courtyard had floor plans and dimensions different from those shown on both maps. It is unfortunate that a densely wooded area precluded complete survey of the western Presidio.

5.4.5 Ground Truthing Excavations at Presidio Los Adaes

The final major stage of the field demonstration was ground truthing. It is the use of independent information to verify, reject, or refine interpretations of geophysical data. Various sources of information can be used in ground truthing, including archaeological excavation, aerial and historic photographs, written documents, historic maps, and (for recent impacts) local informants (Hargrave 2006). In most archaeological situations, ground truthing focuses on the interpretation of discrete geophysical anomalies as particular feature types, or less commonly, deposits (such as midden) or objects (large artifacts). Factors that complicate interpretation of geophysical data—

and thus, make ground truthing almost essential-- include equifinality, superpositioning, site formation processes, recent adverse impacts, and the unique character of archaeological sites.

Equifinality is a process wherein different activities or events can have similar results. It limits the specificity of interpretations of nearly all archaeological deposits, and is particularly troubling for interpretations based on geophysical data. For example, a magnetic gradient survey might detect a number of small anomalies characterized by slightly elevated magnetic values. Their size and shape might be consistent with pits that were used for storage and other purposes throughout much of prehistory, and which probably represent the single most common type of feature throughout much of the US. Unfortunately, such anomalies could be caused by a number of things, including small pieces of ferrous metal at a shallow depth, less magnetic but larger rocks, natural depressions representing concentrations of relatively magnetic topsoil, etc., (Bevan 1998). Pits are a common feature type, but so too are the other possible causes of "pit-like" anomalies.

Super-positioning and stratification are fundamental archaeological concepts. A deposit that occurs on top (and often cutting into) a second deposit is said to superimpose it, and based on the principle of stratification, is assumed to be later. It may be later by a few days or a few centuries. Similarly, the features may represent the same functional type or be very different. Most geophysical techniques might not distinguish between the two deposits, but instead, simply detect the combined result. Two slightly overlapping pits might have a size and shape consistent with a grave; a tight cluster of overlapping pits might be misinterpreted as a house, and so forth. The more intensively a site was occupied, the more likely it is that super-positioning will complicate efforts to assign anomalies to feature categories.

Site formation processes (Schiffer 1987) include a variety of natural and cultural processes (soil development, sheet erosion, gullying, plowing, excavation, compaction, burning, discard) that further alter and complicate 3-dimensional deposits that most methods can only image as horizontal variation in the amplitude of one geophysical property.

A final factor that complicates the interpretation of geophysical data is the unique character of archaeological sites. The manner in which features and other deposits will be manifest in geophysical data is a result of interaction between a site's many characteristics, including soil texture, chemical makeup, and moisture; bedrock and rock inclusions in the soil; as well as the archaeological deposits. This uniqueness is why a particular technique can detect certain categories of features at one site but not another.

Given these factors, it is a rare site that can be confidently interpreted based solely on geophysical data. Thoughtful ground truthing can dramatically enhance the interpretability of geophysical data at virtually all sites. It is for these reasons that ground truthing is an important component of an integrated multi-sensor approach to charactering archaeological sites.

Selecting Targets for Ground Truthing

Historic archaeologists sometimes have access to period maps or textual descriptions of the site they are investigating; this is particularly true for military sites and the public sectors of important settlements (maps of early farmsteads are rare until the appearance of subscription county atlases in the later 19th century, and even then, are biased in favor of more affluence

landowners). Los Adaes researchers are fortunate in having access to two historic maps of the fort. The two maps have many similarities but also a number of important differences. It was uncertain which map is most accurate, or whether both maps accurately depict the fort at different points in time. Despite this uncertainty, the Los Adaes maps represented a valuable source for hypotheses about the presence, nature, and location of features such as the palisades, bastions, and internal structures.

Where no map is available, interpretations of geophysical anomalies must be based on knowledge of the feature types that characterize the time periods represented at the site and an understanding of how such features might be manifest in the data collected using the various sensors. For the latter, some expectations are based on an understanding of how the "geophysical record" of a site is formed (Dalan 2006; Kvamme 2006). Researchers also rely on results of previous investigations that focused on similar deposits at sites with similar soils and other key properties.

Had the Los Adaes historic maps not been available, our expectations for the fort would have been more general. For example, palisades were often constructed from posts held upright by the sides of a narrow trench or individual post-holes. Many previously investigated sites have demonstrated that those foundation trenches or holes eventually collect organically rich topsoil or midden, and are detectable in magnetic, magnetic susceptibility, and often other geophysical surveys.

Selection of Ground Truthing Targets at Los Adaes

The goal of the ground truthing component of this project was to demonstrate how to evaluate interpretations of the geophysical data. In general, this involved locating and excavating a test unit to determine if an anomaly was correctly identified as a particular type of archaeological feature or deposit. This was more easily accomplished at Los Adaes than at many sites because of the clear patterning seen in the geophysical data, and our ability to compare many anomalies to features depicted on the historic maps. For example, large portions of the fort's six-sided palisade appeared in the data for most sensor types, and its overall configuration was so distinctive that there was little doubt that the linear anomalies in question had been correctly identified. Other anomalies, however, posed the kinds of interpretive challenges one confronts at less strongly structured, historically documented sites. We did not choose Los Adaes as the demonstration site to make the ground truthing "easy", but rather, because the site is intrinsically interesting to most of the demonstration participants and future readers.

Ground Truthing Methods

Our ground truthing effort was highly realistic in terms of several important constraints. Project funds would not support a large-scale excavation effort. Only $25,000 had been allocated for the ground truthing, and a significant portion of that had to be reserved for a detailed analysis of the excavated artifacts and preparation of a report that would meet the Louisiana SHPO requirements. Even if more funds had been available, large scale excavations would not have been consistent with the State's management objectives of site preservation and interpretation

based on minimally destructive investigations. One of the important benefits of the integrated multi-sensor approach is the potential to characterize a site based on geophysical survey and very limited but carefully targeted excavation. Thus, an ancillary goal was to evaluate our interpretations of the geophysical data with as little impact to the site as possible. The project team decided that the excavation of at most 15 m2 would be a good balance between these goals, and that amount of excavation was acceptable to the State. The ground truthing was conducted by Dr. George Avery, director of the CRM program at Stephen F. Austin State University (SFASU), and formerly the resident archaeologist for Los Adaes. His previous knowledge of the site enhanced the amount of information that would result from the small-scale excavations. Additionally, Avery had for many years been a colleague with Dr. Pete Gregory, who had done relatively extensive excavations at Los Adaes. Gregory was willing to serve as an unpaid consultant to the project, and his advice was invaluable.

It was desirable to excavate small units to allow as many anomalies as possible to be investigated. One by one meter units were viewed as the smallest size that would allow a reasonable opportunity to identify the type of features associated with anomalies. Previous experience (including ground truthing conducted during SERDP Project RC-1263) indicated that it would be critical to locate units where they could yield the greatest amount of information, but even then, it would likely not be possible to determine the size, depth, contents, and functional type of some features by excavating a single unit. Our research design and contract with SFASU allowed some units to be expanded, so long as this did not increase the overall limit of 15 m2. All units were excavated in ten centimeter levels. Two units were 30 cm deep, one unit was only excavated to 10 centimeters below surface (bs), and all of the other units were excavated to 20 cm bs. Had the deposits at Los Adaes not been located immediately below the surface, it would have been necessary to dig deeper and therefore, larger units.

An important part of our ground truthing strategy was to use soil cores to "fine-tune" the location of units before excavation began. This was to ensure that no error had been made in positioning the unit, and where appropriate, to position units on the edges of features. Units that intersect feature margins are often much more information about feature shape and type than units entirely located within a feature. We also planned to use soil cores to determine the overall dimensions, shapes, and depths of features; and to determine if distinct fill zones were present. Such zones are sometimes related to discrete filling episodes, and these can provide a basis for more nuanced inferences about feature function, secondary use (often for discard), chronology, season of use, and eventual abandonment. One of the realities of field archaeology and particularly, CRM archaeology is that fieldwork has to fit into other schedules and often cannot be conducted at the optimal time. We were disappointed to find that the ground was so dry that soil cores could only be inserted using a heavy hammer and considerable effort. This precluded the use of transects of closely spaced cores to fine tune unit location. We did find, however, that soil cores yielded information well worth the time and effort they required when a unit was partially or completely excavated. By that stage, the excavators were very familiar with the color, texture, and contents of the fill, and could interpret the very small diameter (ca. 0.75 inch) soil cores. Had the ground been a little harder, or the overlying deposits thicker, we would not have been able to use soil cores, and that would have significantly limited our understanding of the deposits.

All excavated fill was water screened through 1/16 inch mesh nylon window screen in the field. The flexible nylon screens were placed inside larger screen assemblies, and standard garden

hoses with pressure attachments were used to help force the dirt through the mesh. Soil was transported from features being excavated to the screening station in buckets. Presoaking soil was needed to expedite the screening process. Most artifacts were not particularly fragile, but many small glass beads were present and their recovery required careful examination of the soil while screening was underway. In the lab, all recovered material was re-screened using 1/4 inch hardware cloth. All material retained in the 1/4 inch screen—including natural rock and organics (roots were abundant) was documented. Modern roots were photographed, weighed and discarded. All other material in the > 1/4 inch fraction was counted and weighed. Cultural material was pulled from the < 1/4 inch fraction in the lab. This included glass beads and fragments of pottery, glass, lithics, metal, diagnostic bone and charred seed/nut remains. The remaining < 1/4 inch sample was then weighed. Artifacts and natural stone were sorted into standard categories used by professional archaeologists who specialize in 18th century mission sites. Ironstone (also called iron rock) was counted and weighed. Such data may be useful in better understanding the magnetic amplitudes associated with some of the Los Adaes features and other deposits. A detailed analysis and interpretation of the artifacts recovered from the excavations is included in a report of the ground truthing excavations submitted to the Louisiana Division of Archaeology (the SHPO) and is available to interested researchers. In the interests of brevity, those data are not included here.

Several factors were taken into account in selecting anomalies for ground truthing. In order to insure that the chosen anomalies would be well-distributed, the fort was divided into “regions” of geophysical interest. These are designated by reference to the nearest bastion or palisade. In some cases, regions are further designated using information from the 1767 map. Several portions of the fort (designated regions F and G) were intentionally avoided. The north palisade and bastion were omitted from consideration because they had been extensively excavated. Structures and adjacent areas in the northwestern portion of the fort were avoided because it was thought that graves might be located near the chapel.

The 9 regions and units excavated to investigate them were:

A - Possible structures near the southwest bastion (units 1, 2, and 3).

B - Possible structures and features near the southeast bastion (Units 4 and 5)

C - A possible entryway north of the southeast bastion (Unit 6)

D - Possible structures (identified as soldier’s barracks) near the eastern palisade (Units 7, 8, and 9)

E - Eastern palisade, possible moat, and other linear features (Units 10, 11, and 12)

H - Area south of the southeast bastion (outside the fort) (Unit 17)

I - Southern palisade (Unit 19)

J - Possible structure (identified as officer’s quarters) near the western palisade (Unit 20 and 21)

Locations for eighteen 1x1 meter units in the nine regions were identified (Table 5-2). The three additional units were selected in case some of the chosen locations were thought to be unsuitable for excavation when inspected in the field. Table 5-2 also indicates the type of

data within which the anomaly was primarily identified (many anomalies appear in multiple data types). Those columns indicate magnetic gradient (Mag), magnetic susceptibility (MS), ground penetrating radar (GPR) and electrical resistance (Res).

Only eleven of the eighteen units initially selected were excavated (Units 1, 2, 3, 4, 6, 7, 9, 10, 11, 12, and 17) and two .5x1 meter units were excavated as additions to Units 6 and 10, and designated (respectively) as Units 6A and 10A. In the field, Avery advocated the importance of testing the southern palisade line since no previous investigations had been located there, and so Unit 19 was excavated in Region J. A structure identified on the 1767 map as the Officer's Quarters (Region K) was also selected in the field for excavation by Units 20 and 21. This brought the total to fourteen 1x1 meter units and two .5x1 meter units, for a combined area of 15 m2 (see Figure 5-17).

Table 5-2. The 18 units initially selected to investigate 9 areas (A-I) of geophysical interest.

Region	Unit	Local_East	Local_North	UTM_E	UTM_N	Mag	MS	GPR	Res
A	1	410.84	557.09	472158.765	3508101.742	x			
A	2	413.54	553.46	472161.416	3508098.048	x	x		
A	3	427.36	563.52	472175.272	3508107.980	x	x		
B	4	450.56	564.29	472198.667	3508108.814	x	x		x
B	5	458.4	562.49	472206.411	3508106.858			x	
C	6	483.27	577.53	472231.278	3508121.851	x	x		
D	7	460.36	582.92	472208.387	3508127.237	x	x		
D	8	465.63	583.24	472213.658	3508127.535	x	x		x
D	9	469.25	581.39	472217.318	3508125.679	x	x		
E	10	479.11	590.89	472227.040	3508135.036	x	x		
E	11	481.38	591.88	472229.456	3508135.904	x	x		
E	12	483.99	601.51	472231.985	3508145.606		x		
F	13	440.44	589.57	472188.574	3508133.795	x	x	x	
G	14	434.78	644.38	472183.110	3508188.273		x		
G	15	436.23	637.42	472184.608	3508181.324	x	x	x	
G	16	440.36	637.92	472188.660	3508181.914	x	x		
H	17	478.23	557.46	472226.163	3508102.109	x		x	
I	18	435.15	600.57	472183.338	3508144.824			x	

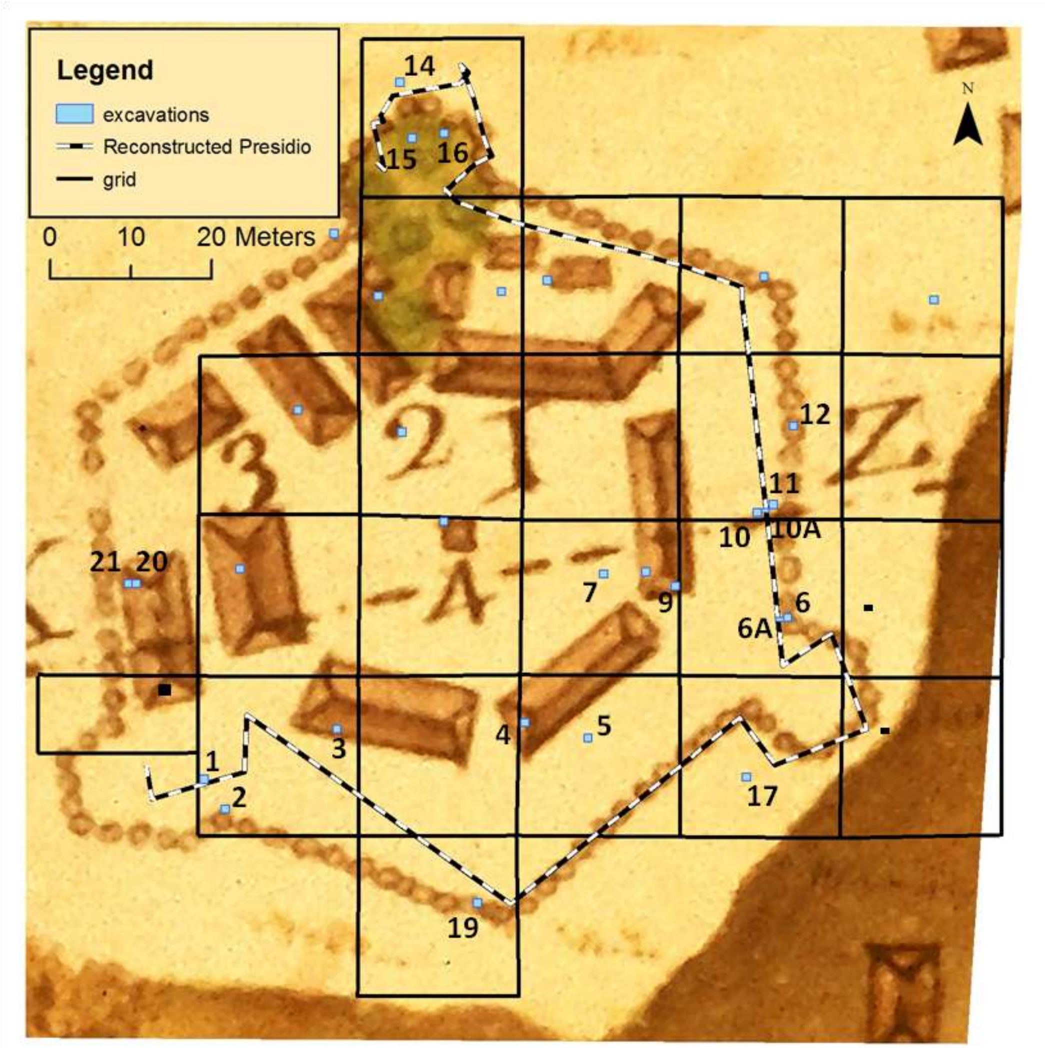


Figure 5-17. Location of the excavated units (blue) relative to the georeferenced 1767 map. The dashed line shows the location of the horizontal wooden beams that represent the reconstructed presidio. All excavated units are numbered, while those that were planned, but not excavated are shown without unit numbers.

Region A: Possible structures near the SW Bastion. Units 1, 2, and 3.

Region A is the area surrounding the southwest bastion, where some magnetic and magnetic susceptibility (MS) anomalies were interpreted as being associated with structures and/or parts of the fort (Figures 5-18 and 5-19). Unit 1 (Figure 5-20) was excavated to determine if a linear, roughly E-W oriented magnetic anomaly was correctly interpreted as the wall of a structure located near the SW bastion. Rejecting that interpretation—and finding evidence that the anomaly was instead associated with the palisade itself would indicate that the historic maps were not properly georeferenced relative to the geophysical data, or were simply inaccurately drawn. As expected, two linear areas of darker soil were observed along the

north and south edges of the unit at 10 cm bs, but they were unaccountably absent at 20 cm bs. Areas of even darker soil were observed in the northeast and southeast corners at 10 cm bs but were not visible at 20 cm bs. Artifact density was moderately high, and soil probes indicated the cultural deposits extended to 80 cm bs. It is likely that the deep cultural deposits encountered in this unit are the result of mounding earth to construct the bastions. On balance, excavation of Unit 1 verified the presence of some kind of linear feature but neither verified or convincingly refuted the interpretation that it was associated with a structure.

Unit 2 (Figure 5-21) was excavated to determine if large (ca. 4 m on a side in the MS data) roughly rectangular anomalies represented a structure within or immediately adjacent to the SW bastion. The anomalies are located just outside the limits of the bastion as shown on the 1720 map but just inside the bastion on the 1767 map. Neither map shows a discrete feature at that location. Unit 2 was excavated to a depth of 30 cm bs. The east wall profile showed evidence of old A and E Horizons not observed in the west wall profile. The ground surface and strata sloped 15 cm across a distance of one meter. Soil probes in the middle and just north of the unit indicated that cultural deposits continued only to 35 cm bs. Overall, available evidence is more consistent with the interpretation that Unit 2 was located within a mounded deposit associated with the bastion rather than within a filled pit. While excavation results are not entirely conclusive, they favor rejection of the interpretation that a structure (other than or in addition to the bastion) was present.

Unit 3 was excavated to determine if an amorphous magnetic and MS anomaly was correctly interpreted as a discrete feature located inside a structure shown on both historic maps (and described in the 1767 map as a barracks). Efforts to position the unit at the edge of the anomaly were successful and the edge of a roughly ovate feature was documented in the northeast portion of the unit at 18 cm bs (Figure 5-22). The feature was heavily burned and contained a high density of cultural material. A soil probe indicated that the feature continued to a depth of 30 cm bs. The east wall profile suggested that this feature was not a pit feature, but rather a pile with the high point located near the northeast corner of the unit. This interpretation would appear to suggest that the structure floor was built up at least 30 cm.

Units 1, 2, and 3 indicated that our interpretations about the presence of discrete features were only partially correct. Most non-architectural features are, in the most general sense, dug into the surrounding matrix. At Los Adaes, the bastions had been constructed by mounding earth to create raised platforms that served as platforms for cannons and as defensive structures. The mounded bastions clearly included discrete piles of material that, in the geophysical data, resemble pit-like features. These small, discrete piles are a kind of feature that is rarely encountered by archaeologists (other than in earthworks), but which may well occur elsewhere at Los Adaes and at other historic earthworks.

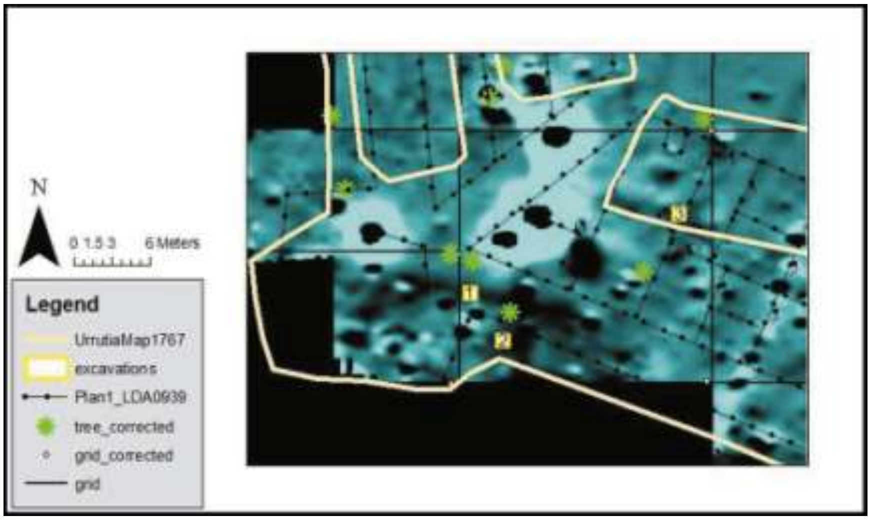


Figure 5-18. Magnetic gradient image of Region A showing the location of Units 1-3.

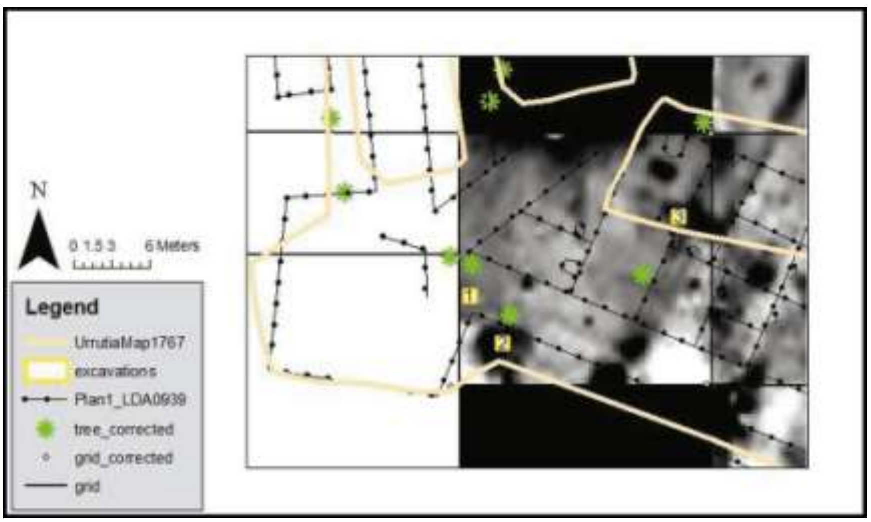


Figure 5-19. Magnetic susceptibility image of Region A showing the location of Units 1-3.

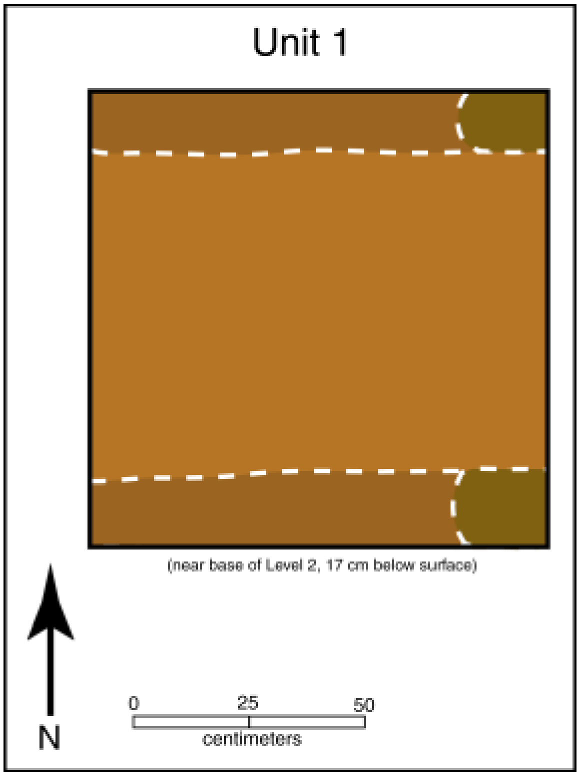


Figure 5-20. Linear anomalies in Unit 1 were visible only to a depth of 17 cm bs.

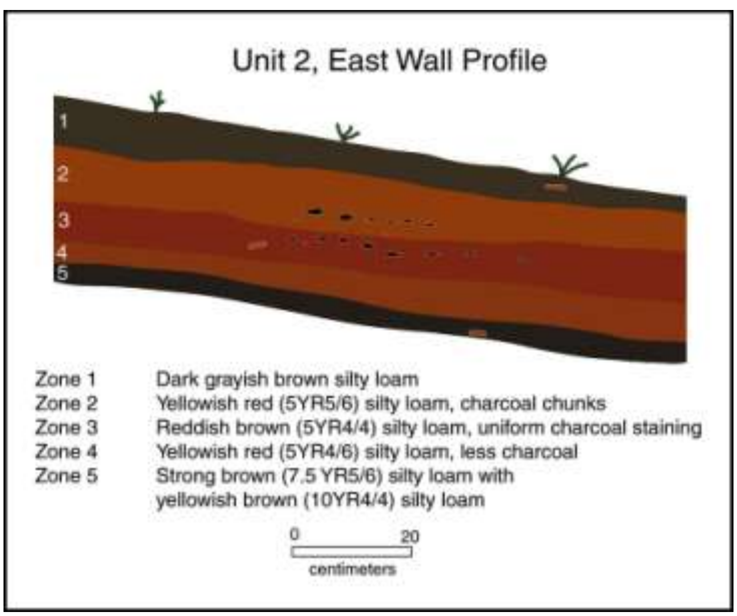


Figure 5-21. Sloping strata in the Unit 2 east profile indicated the unit was located within mounded earth rather than a pit.

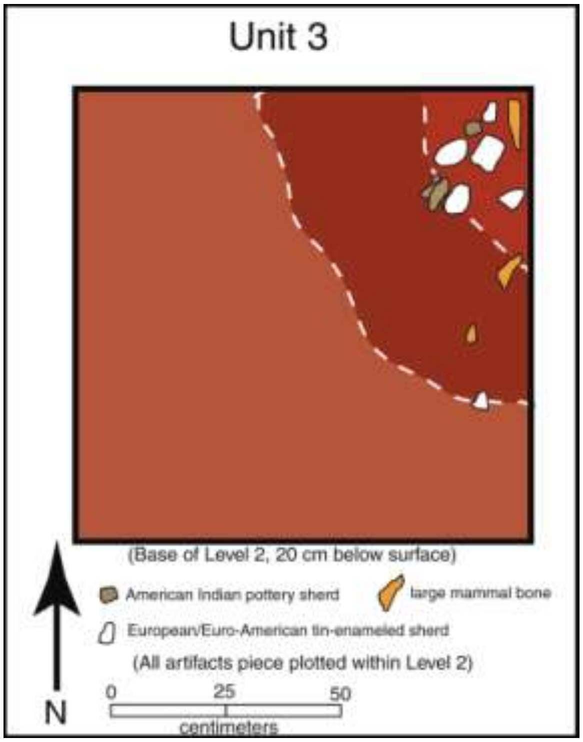


Figure 5-22. Unit 3 verified the presence of a feature representing a pile of cultural debris.

Region B—Possible Structures and Associated Features in SE, Units 4 and 5

Region B (Figures 5-23 and 5-24) includes one of the barracks depicted on the 1767 map and the planned location for another barracks building as depicted on the 1720 architect's plan. Several anomalies in the magnetometry and MS data are interpreted as being associated with those structures.

Unit 4 (Figure 5-26) was excavated to test our interpretation that a large round-to-oval feature identified in magnetometry, MS, and electrical resistance represented a discrete feature inside a structure. The anomaly is centered in the west end of a structure on the 1767 map, and is also within the large planned barracks depicted on the 1720 architect's plan. The anomaly was also consistent with the dimensions of disturbance caused by tree throws, several of which Avery had excavated previously. Excavation of Unit 4 revealed large quantities of *in situ* burnt clay, some of it with smoothed surfaces, and all of it with fibrous inclusions. Charcoal was scattered throughout both excavation levels. Two charcoal concentrations were present. Several large wrought iron nails were recovered, and a concentration of tabular sandstone was thought to represent a boundary of some sort. Soil probing along the eastern side of the unit revealed that the cultural deposits ended at 25 cm bs. Additional probing to the east of the unit did not identify a continuation of the burned soils and high density of burnt clay. Our interpretation of the geophysical data as a discrete feature was confirmed, and additional information resulting from excavation suggested it might be a collapsed earth oven. An earth oven is depicted in front of the Governor's house on the drawing of building facades that accompanies the 1767 map. Another interpretation is that the feature in Unit 4 is a prepared

hearth area. Historical information indicates that the barracks were heated using braziers; in this case, large metal containers sitting on a prepared clay surface (not by fireplaces with chimneys).

Unit 5 was one of the few units that ground truthed interpretations based on GPR anomalies (GPR at Los Adaes was less informative than the other methods). The unit was targeted on a strong reflection detected in the GPR profiles and slice maps (Figure 5-25). It was recognized that this could be a cultural feature or a natural disturbance. It appeared that the feature was buried at roughly 25 cm bs, but the depth calculations were based on very shallow hyperbolas and their accuracy was uncertain. Excavation revealed that the anomaly was caused by a group of four old 1x1 m test units that Avery had excavated to investigate a tree throw. Those units had been excavated to 20 cm bs, suggesting that the estimated depth of 25 cm had been quite accurate.

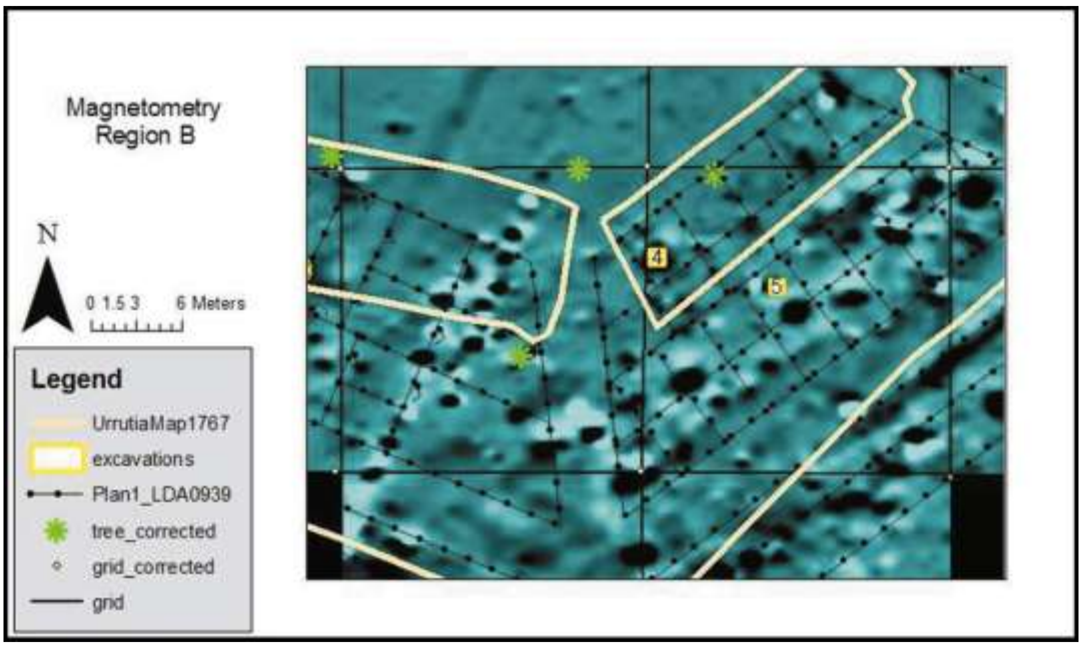


Figure 5-23. Magnetic gradient image of Region B showing the location of Units 4 and 5.

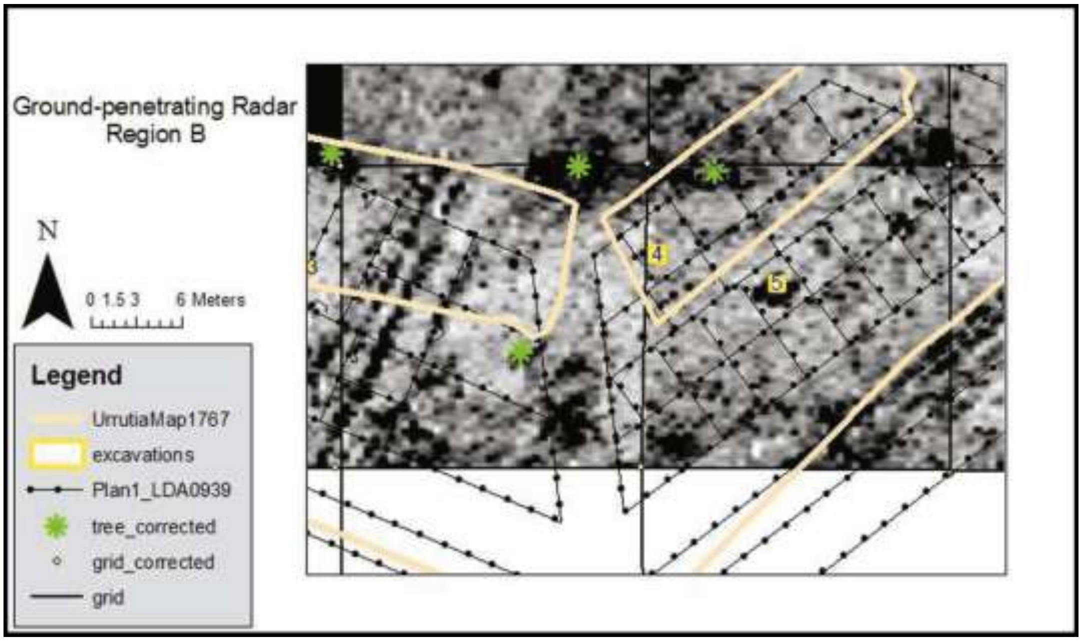


Figure 5-24. GPR image of Region B showing the location of Units 4 and 5.

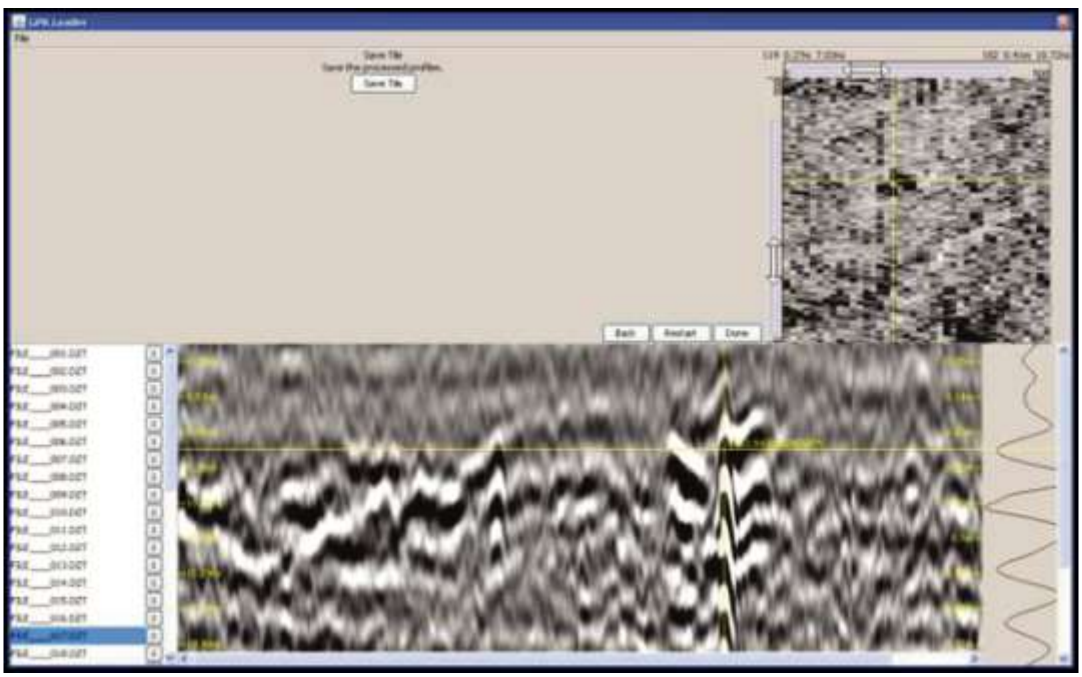


Figure 5-25. *ArchaeoFusion* screen image showing time slice (above) and radar profile (below) used to identify and estimate depth of targeted feature in Unit 5.

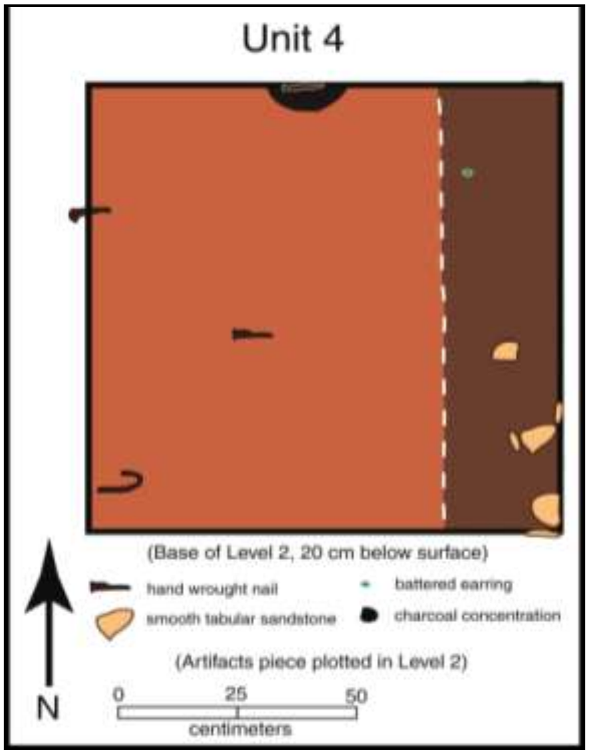


Figure 5-26. Floor of Unit 4 showing feature interpreted as a collapsed earth oven or platform for a brazier.

Region C—Possible Entryway north of SE Bastion, Unit 6

Region C is located along the palisade just north of the SE bastion, where the 1720 map shows an entryway into the fort (Figures 5-27 and 5-28). Unit 6 (Figure 5-29) was located in an area where the magnetometry data showed a very distinct gap in the palisade that was interpreted as the entry (in the geophysical data, the wall almost completely disappears, but there is a very subtle linear anomaly that remains). Magnetic susceptibility data also show a fainter line here, but no distinct gap. We recognized the possibility that this gap was a result of Gregory's earlier excavations.

Excavation of the first two levels of Unit 6 revealed what appeared to be the palisade's wall trench. Unit 6A was excavated to more fully define the trench's width. Soft, sterile soil and flagging tape encountered in the northwest portion of Level 1 in Unit 6 and in the northern of Unit 6A represented portions of an earlier excavation unit. The wall trench was clearly defined in both units at 20 cm bs. A soil probe in the middle of the wall trench indicated that the feature continued to a depth of 95 cm bs. Cultural deposits on either side of the wall trench continued to depths of 32 cm bs in Unit 6A and 42 cm bs in Unit 6. On balance, ground truthing demonstrated that geophysical indications of an entryway are almost certainly a result of previous excavations.

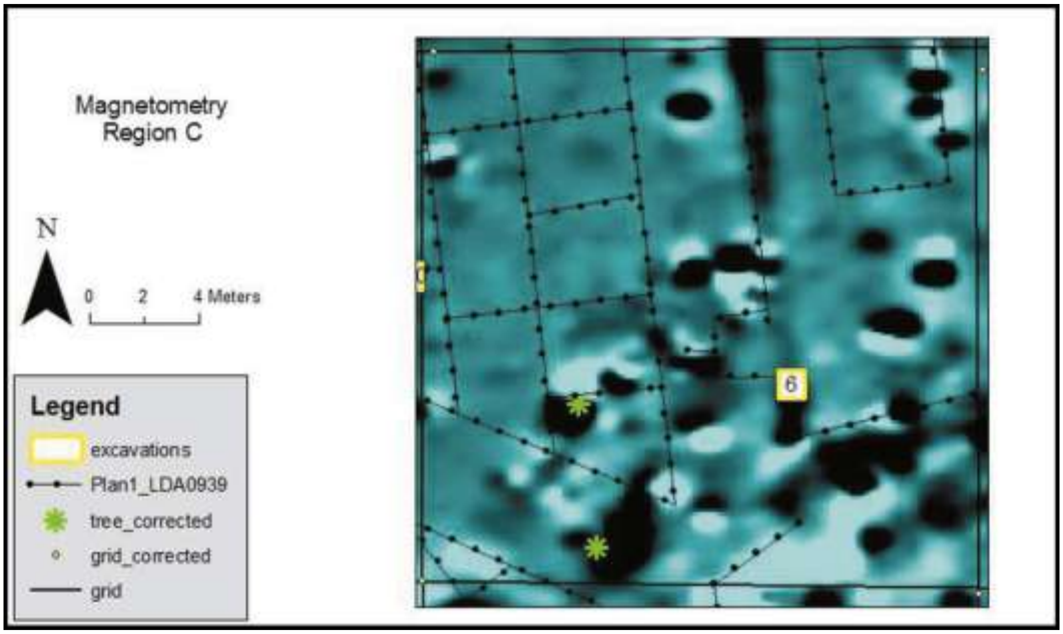


Figure 5-27. Magnetic gradient image showing the location of Unit 6 in Region C.

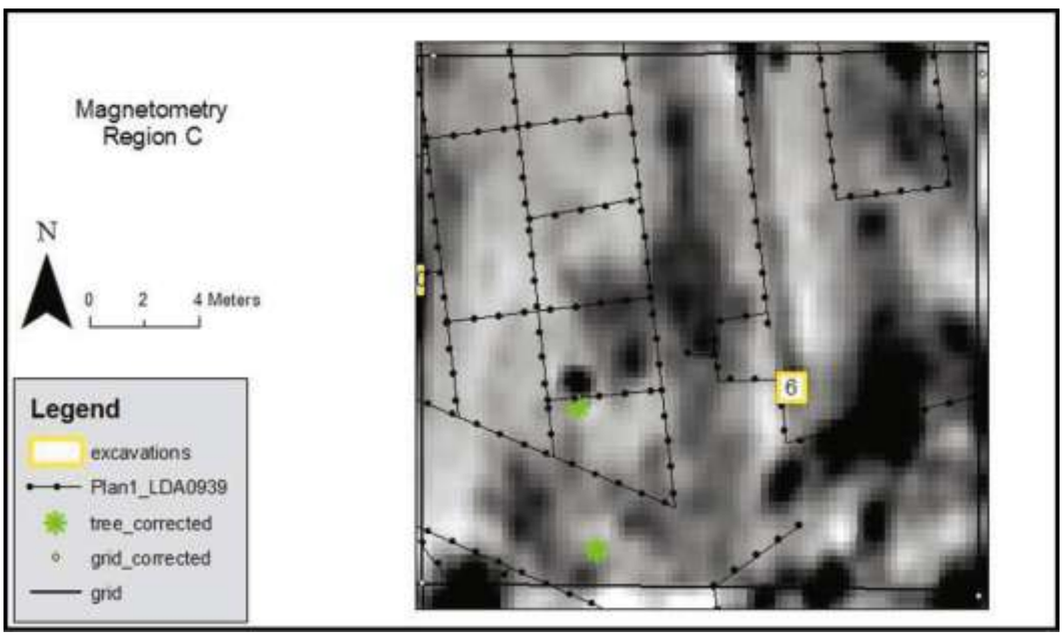


Figure 5-28. Magnetic susceptibility image showing the location of Unit 6 in Region C.

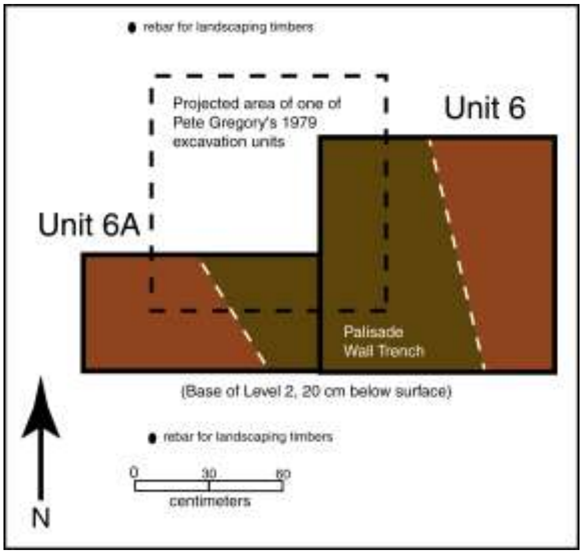


Figure 5-29. Units 6 and 6A revealed that an old excavation unit accounted for the apparent entry.

Region D—Soldier's Barracks, Units 7, 8, and 9

Region D (Figures 5-31, 5-32, and 5-33) includes a number of anomalies that are, as a group, interpreted as features associated with a structure depicted on both of the historic maps. The 1720 map depicts a trapezoidal structure, whereas the building shown on the 1767 map is more rectangular. The distribution of anomalies does not support one shape over the other. Most of the anomalies are similarly amorphous, making it difficult to assign them to specific feature types. Unit 7 (Figure 5-30) targeted one of the more distinctive anomalies. It was linear and oriented parallel to much stronger linear anomalies located further to the east. The Unit 7 anomaly was interpreted as the western edge of an architectural component, possibly a covered walkway or porch extending toward the center of the compound like those depicted by the 1767 drawing of building facades. Unit 7 was excavated in two levels to a depth of 20 cm bs, but no linear features were observed. A lens of dark grayish brown loam with small charcoal chunks was located in Level 2 and probing indicated that the deposit continued another 5 cm. The compact nature of the southern half of the unit at 20 cm bs suggested the possible presence of a prepared surface. An unusually large proportion of Native American sherds were recovered (98% of the 416 sherds). Evidence for gunflint maintenance was strong with 47 fragments of chipping debris. Glass beads (n=34) and glass containers were also well represented.

Unit 8 was targeted on a high contrast MS and magnetic anomaly that was very similar to the one investigated by Unit 4. That unit had revealed a definite feature, one interpreted as being related to indoor heating. Given its similar character and position within a structure, we assumed the Unit 8 anomaly would represent the same feature type. A soil probe revealed deposits of burned soil to roughly 28 cm bs, and natural deposits below that. This represented adequate verification, and Unit 8 was not excavated. Investigation of these two

anomalies provided a sound basis for us to assume that several very similar anomalies located inside other structures represented the same type of feature

Unit 9 (Figure 5-34) focused on a strong linear MS anomaly interpreted as the eastern wall of the barracks. Two levels were excavated and a linear feature was observed along the unit's west wall at 20 cm bs. The feature may represent the wall trench for the west wall of the barracks. A charcoal concentration about 20 cm in diameter and first observed at the base of Level 1 may indicate a post mold. The large number of sandstone fragments recovered from the unit supports the presence of a structure. Pete Gregory has maintained that these small, tabular sandstone fragments were used as chinking in the walls of the structures (Pete Gregory, personal communication to George Avery). The sandstone does not occur naturally in the immediate area of the fort, but there is a sandstone outcrop located within 2 miles to the southwest near highway 21, just east of the town of Robeline. The cultural material associated with Unit 9 was similar to that of Unit 7 (see Table 5-3), with large amounts of all classes of artifacts. Unit 9 was the only unit that produced burnt mussel shell. Unit 9 also had the greatest diversity of metal artifacts recovered during this project, including hand wrought nails, gun parts, horse gear, and lead shot. All of these findings are consistent with the unit being located inside a barracks.

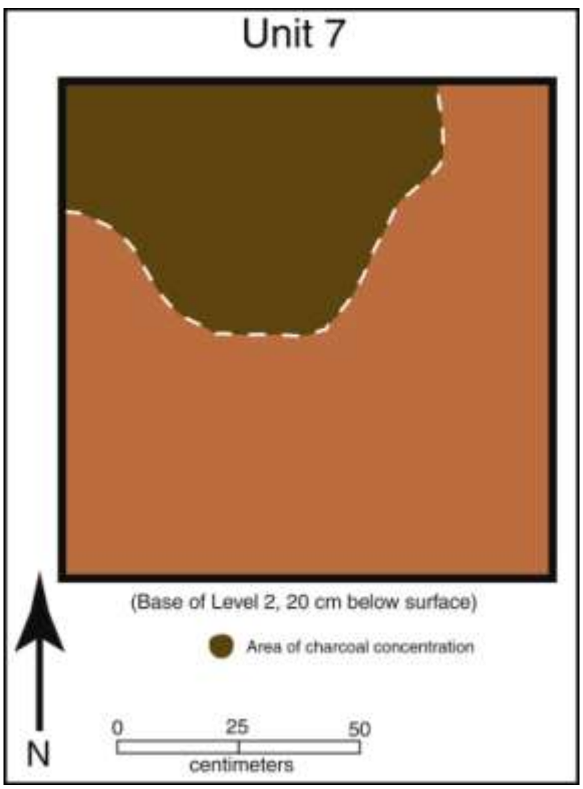


Figure 5-30. Excavation of Unit 7 revealed a charcoal concentration associated with a prepared floor at 20 cm bs.

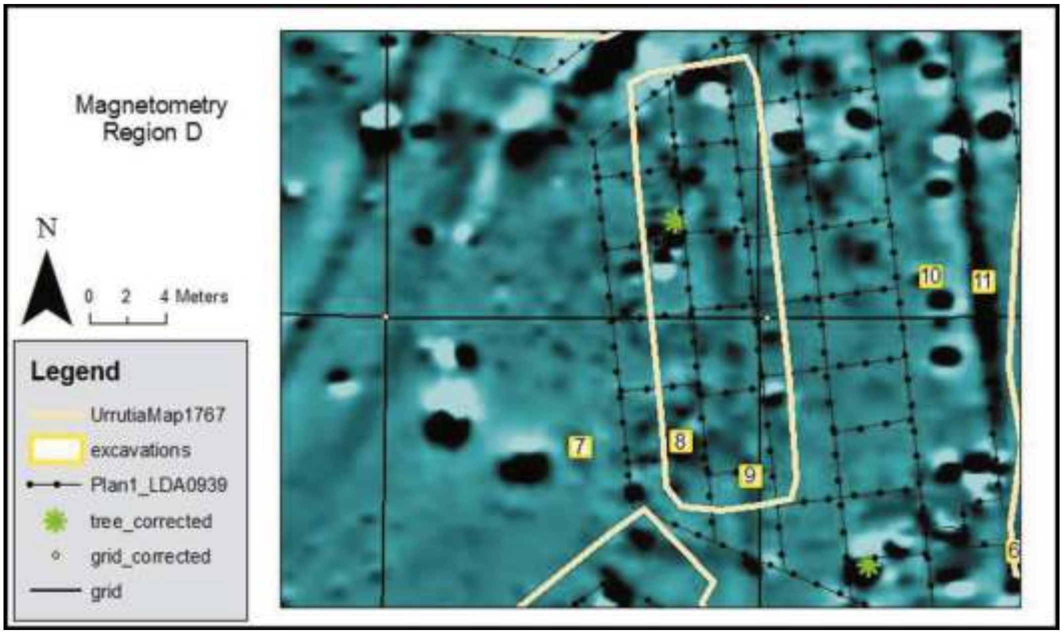


Figure 5-31. Magnetic gradient image of Region D showing the location of units 7-11.

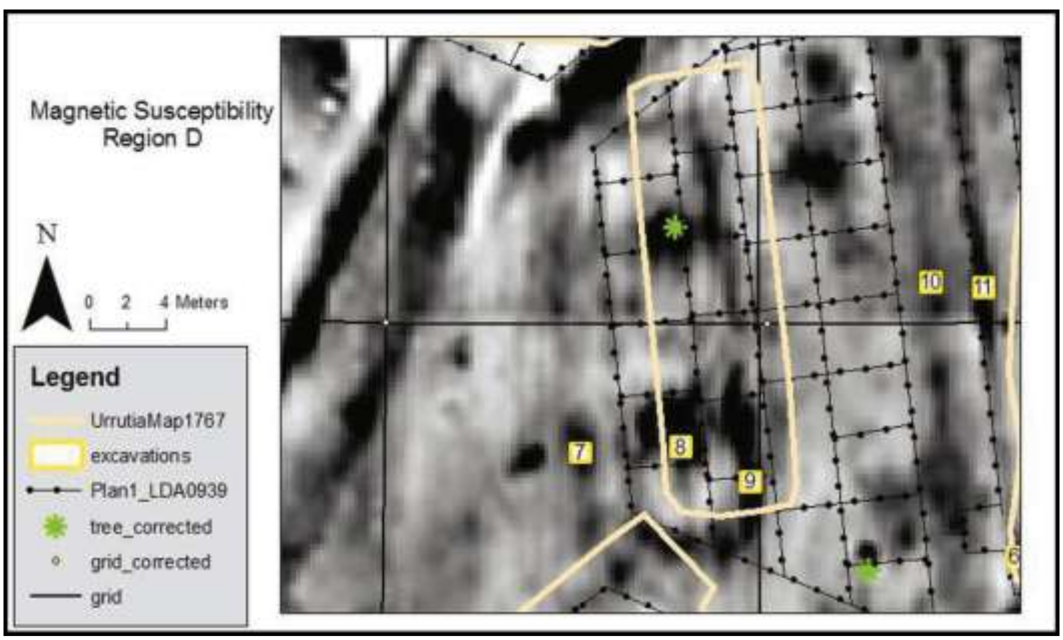


Figure 5-32. Magnetic susceptibility image of Region D showing the location of units 7-11.

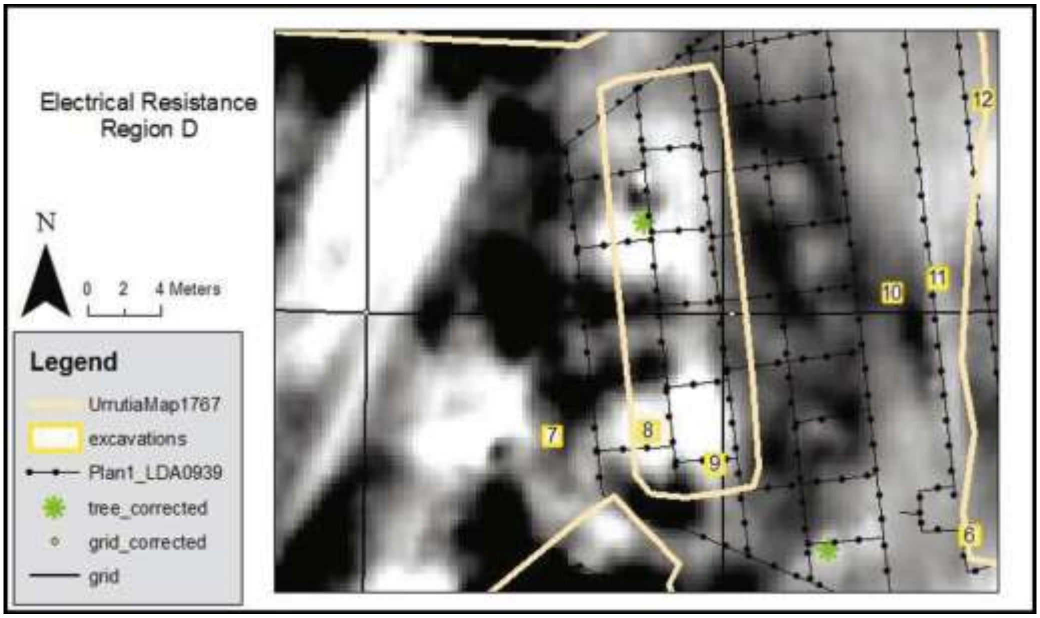


Figure 5-33. Electrical resistance image of Region D showing the location of units 7-11.

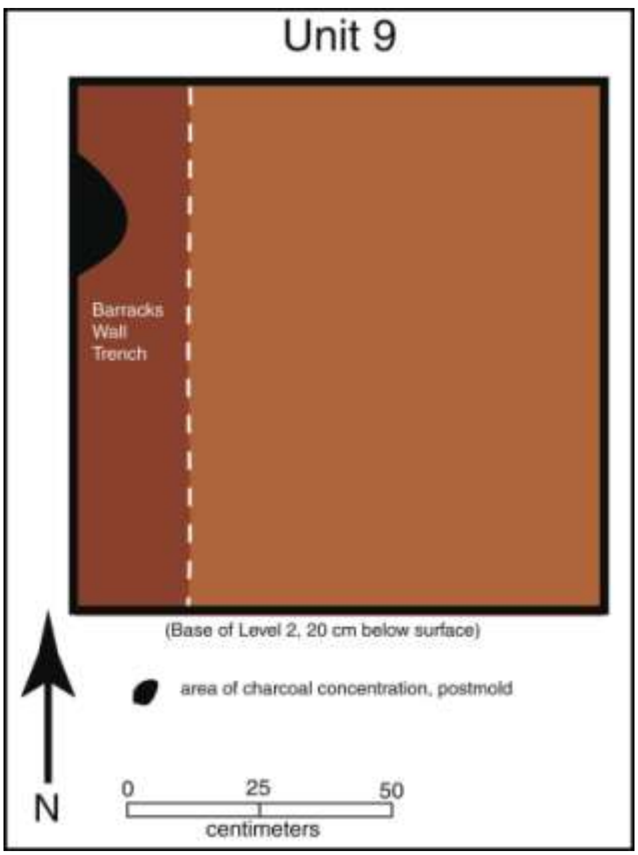


Figure 5-34. Wall trench associated with eastern wall of a barracks detected in Unit 9.

Region E—Eastern Palisade and Possible Moat, Units 10, 11 and 12

Region E (Figures 5-35 and 5-36) includes the eastern palisade and (based on the 1720 plan) a moat. Units 10 and 11 (Figure 5-37) were placed on either side of the horizontal beams that convey the fort's overall shape to visitors. Unit 11 was positioned about one m east of the beams to test our interpretation that a strong linear anomaly in the MS and magnetic data was the palisade. Unit 10 was positioned about 2 m west of the beams to ground truth our interpretation of a weak MS anomaly as a wall associated with the soldier's barracks depicted in the 1720 plan. Units 10 and 11 proved to be so different that a 1x.5 m unit designated 10A was excavated to connect them. The three units revealed the palisade's wall trench, and prepared clay surfaces on either side of that feature. Fully preserved, unburned wood fragments were found at 18 cm bs, within the prepared clay surface in Unit 10A. A soil probe indicated that the wall trench continued to a depth of 86 cm bs. Moderate amounts of a wide range of artifacts were recovered in all three units. No evidence of the faint linear anomaly was identified in Unit 10.

A parallel but very low contrast (faint) linear anomaly in the MS data located about 4 m to the east was interpreted as the moat, and that interpretation was ground truthed by Unit 12. That unit encountered a cultural feature that is probably the defensive ditch or moat that is indicated on the 1720 architect's plan (it is not shown on the 1767 map). Unit 12 was only excavated to 10 cm bs. The soil was compact red clay with inclusions of loamy soils, and artifact density was high. Soil probes demonstrated that the feature continued to a depth of 75 cm bs. A gley soil encountered at 55 to 65 cm bs indicated that water had stood there and evaporated. A series of soil probes were excavated east of the unit. At 2.5 meters east of the unit, there was evidence of what appeared to be gley soil deposits at 45cm bs. The gley soil was absent in a probe located 4.5 meters east of Unit 12.

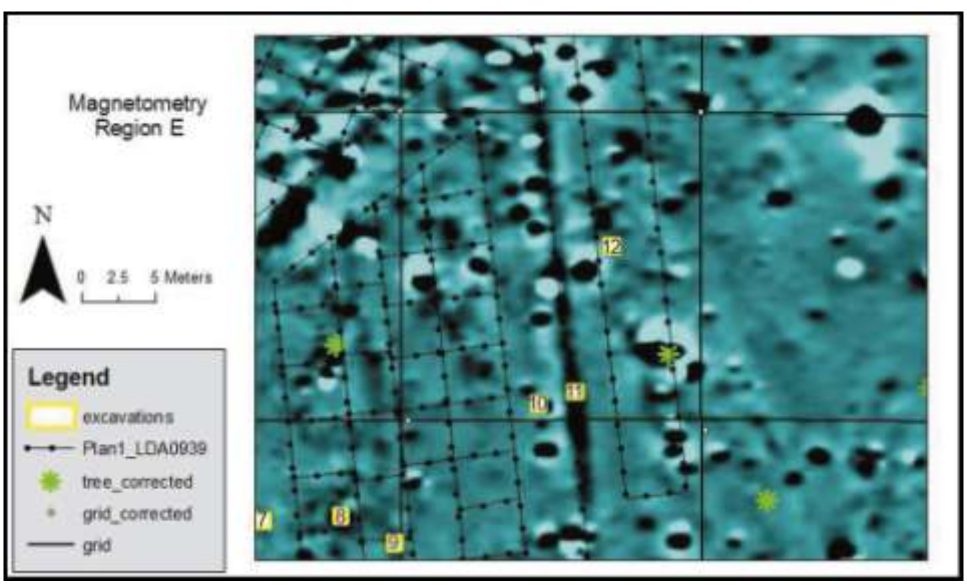


Figure 5-35. Magnetic gradient image showing the location of units 7-12 in Region E.

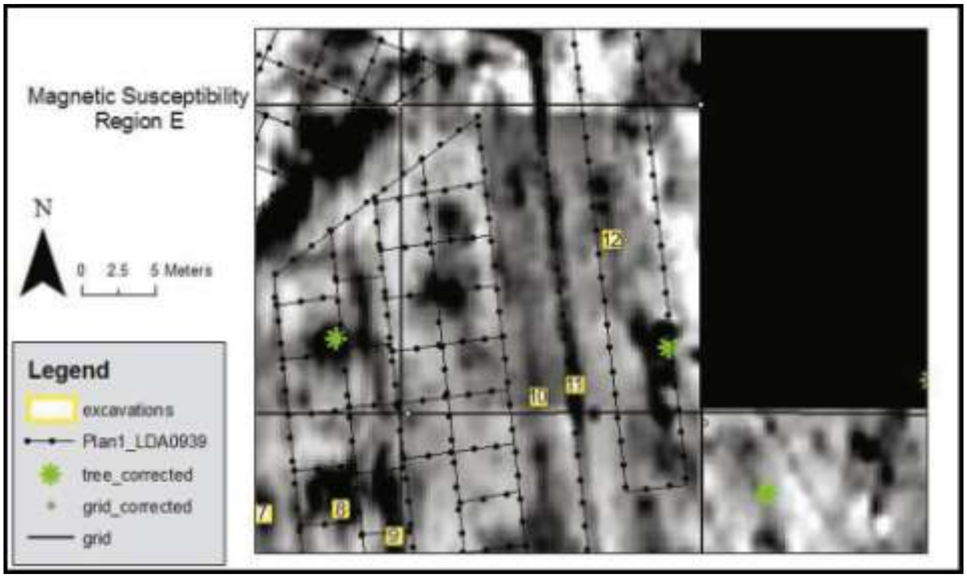


Figure 5-36. Magnetic susceptibility image showing the location of units 7-12 in Region E.

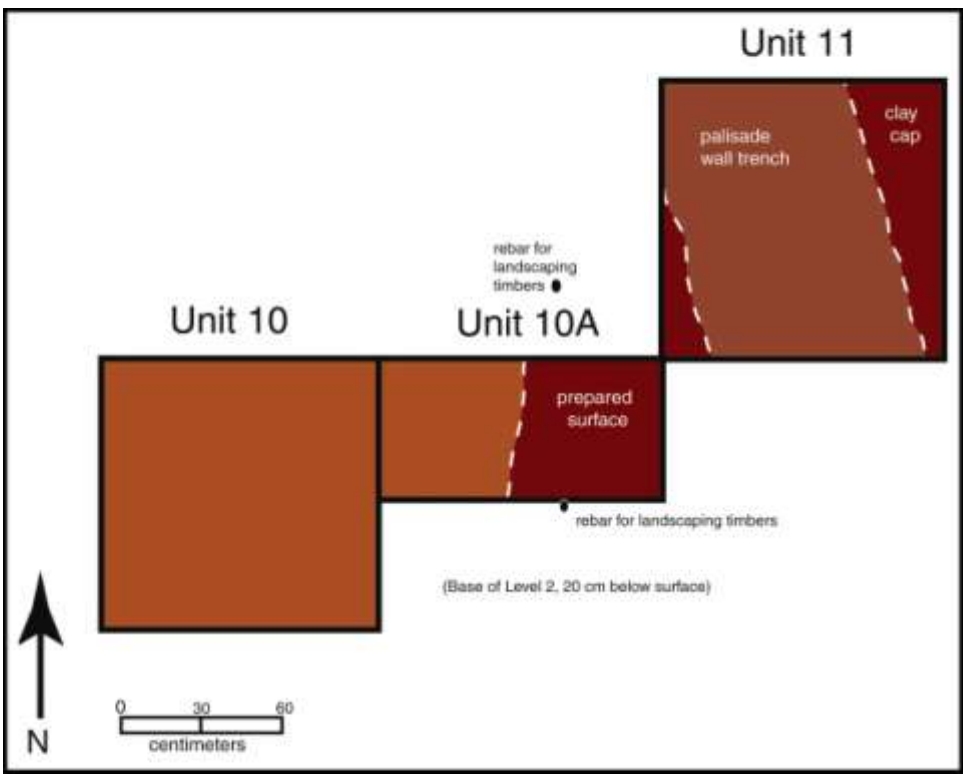


Figure 5-37. Prepared clay surfaces were identified on either side of the eastern palisade detected in Units 10A and 11.

Region H—Small Feature south of SE Bastion, Unit 17

Region H (Figures 5-38 and 5-39) refers to a small area directly south of the SE bastion that was interpreted as a discrete feature of uncertain type. Unit 17 (Figure 5-40) was targeted on the apex of a reflection hyperbola in GPR profile 17 (grid # 4), at a depth of about 10 cm. Because the depth estimate was based on only a few very shallow hyperbolas and could be inaccurate, Unit 17 was excavated to 20cm bs. It produced large amounts of all artifact categories, particularly animal bone, suggesting that the area was used for refuse discard. Ceramics were particularly numerous with 97% being Native American—very similar to the percentage for Unit 9 associated with the outside of a barracks building. The average for the rest of the site is around 90%. While much of the animal bone in the other units was very fragmentary, whole elements were recovered in Unit 17. The soil color (10YR3/2, very dark grayish brown) was darker than in any other unit and clearly indicated midden deposits. A concentration of large mammal bones was present in Level 2 (10-20 cm bs), but no discrete features that would explain the GPR anomaly were visible.

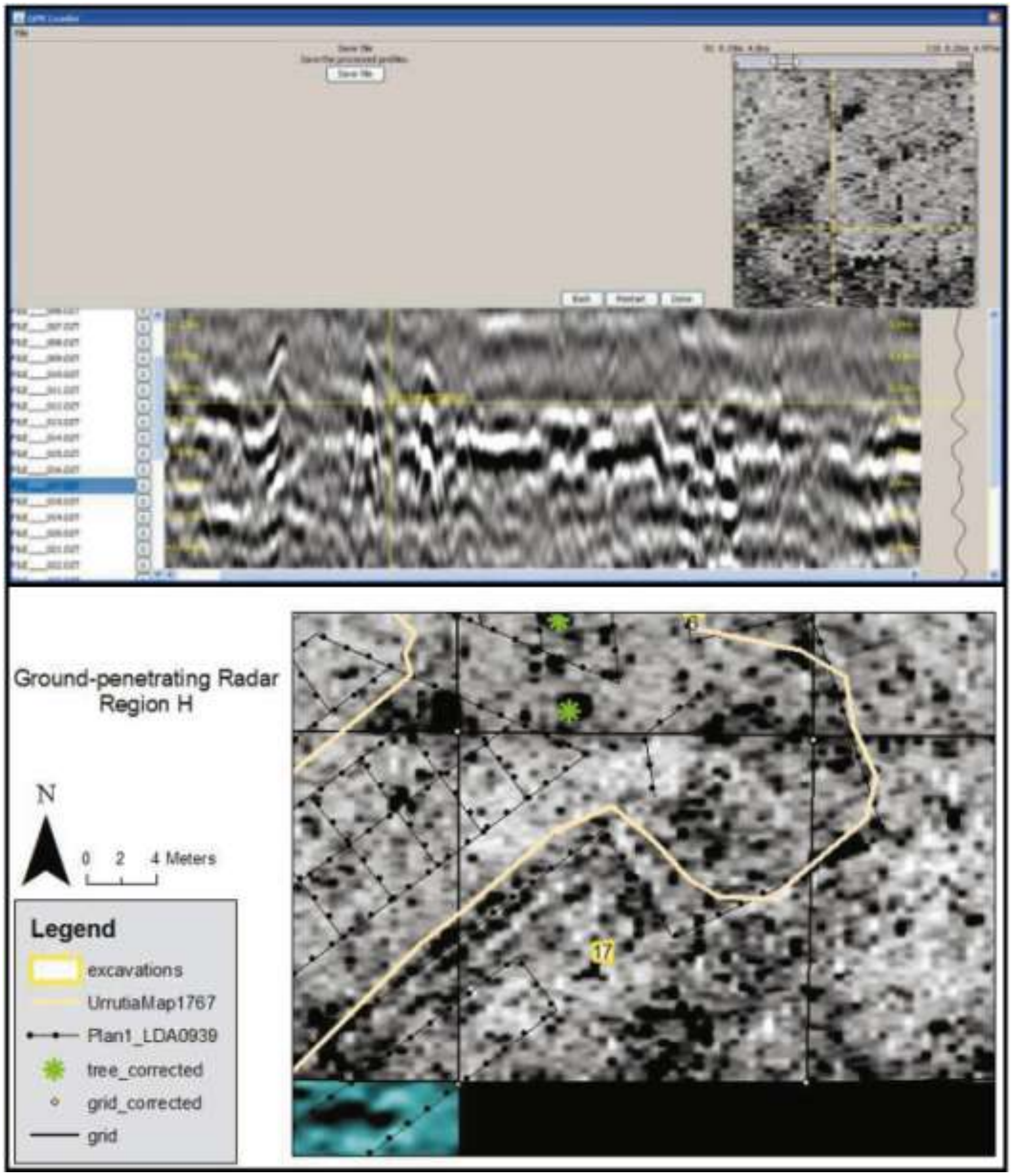


Figure 5-38. *ArchaeoFusion* screen image showing (below) time slice and (above) radar profile used to identify and estimate depth of targeted feature in Unit 17.

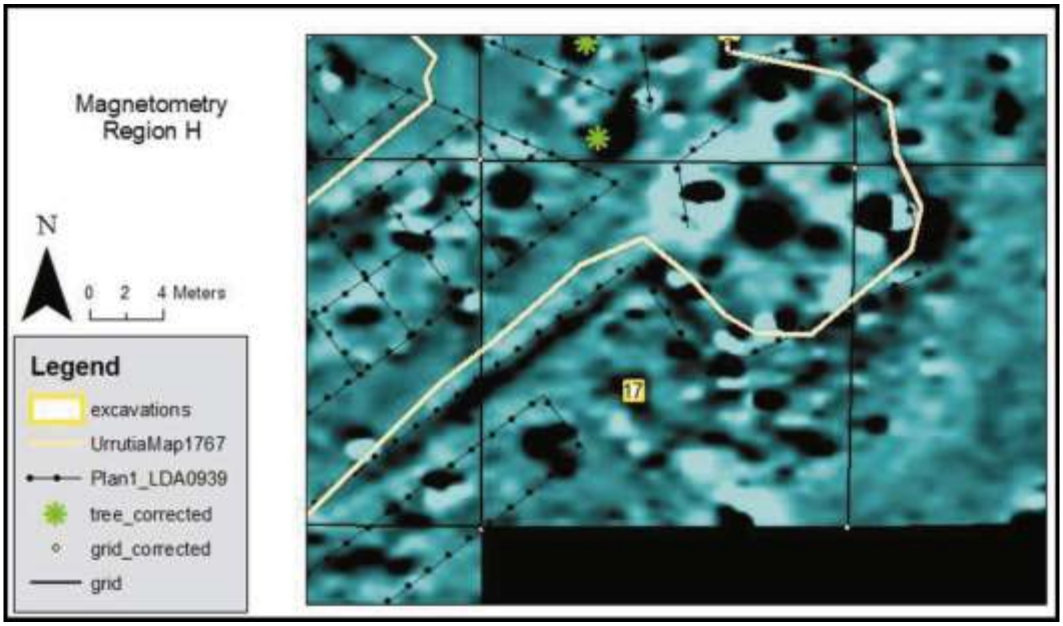


Figure 5-39. Magnetic gradient image showing the location of Unit 17 in Region H.

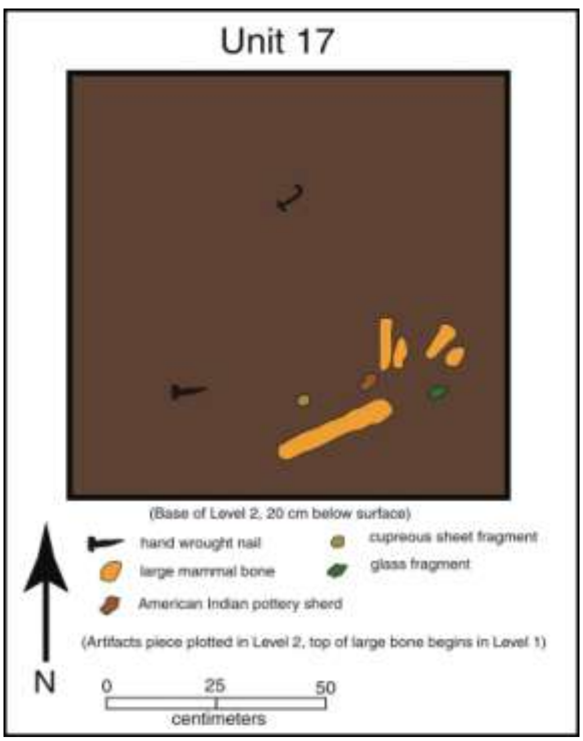


Figure 5-40: Unit 17 investigated a GPR and MS anomaly interpreted as a discrete feature of uncertain type that proved to be a rich midden deposit.

Region I—Southern Palisade of Presidio, Unit 19

One of the most dramatic results of the geophysical study was the delineation of the fort's southern palisade. This wall was clearly defined by magnetometry, MS, and electrical resistance data (Figure 5-41). There had been no previous archaeological investigations in this area, and the location of the landscaping timbers marking the southern wall had been somewhat conjectural. Pete Gregory had used his previous excavations of the southeast bastion as a basis for positioning horizontal beams marking the eastern portion of the southern palisade. The geophysical survey indicated that he had been quite accurate up to and including the east end of the NW SE oriented portion of the southern palisade. The geophysical data indicate, however, that from that point westward, the wood beams are located too far north (Figure 5-42). Unit 19 was excavated to ground truth our interpretation of the southwestern palisade's actual location.

Unit 19 (Figure 5-43) was excavated to 20 cm bs. At that depth, a faint outline of darker deposits was visible extending from the northwest corner to the southeast corner. Rather than excavate another level, a series of soil probes were placed from the northeast corner of the unit to one meter southwest of the southwestern corner of the unit. The presence of a wall trench was clearly visible in the profile drawn from the soil probe information (Figure 5-44). The maximum depth of the cultural deposits was 125 cm bs. Artifact density was moderate to high in Unit 19 (Table 5-3), reflecting generalized dumping.

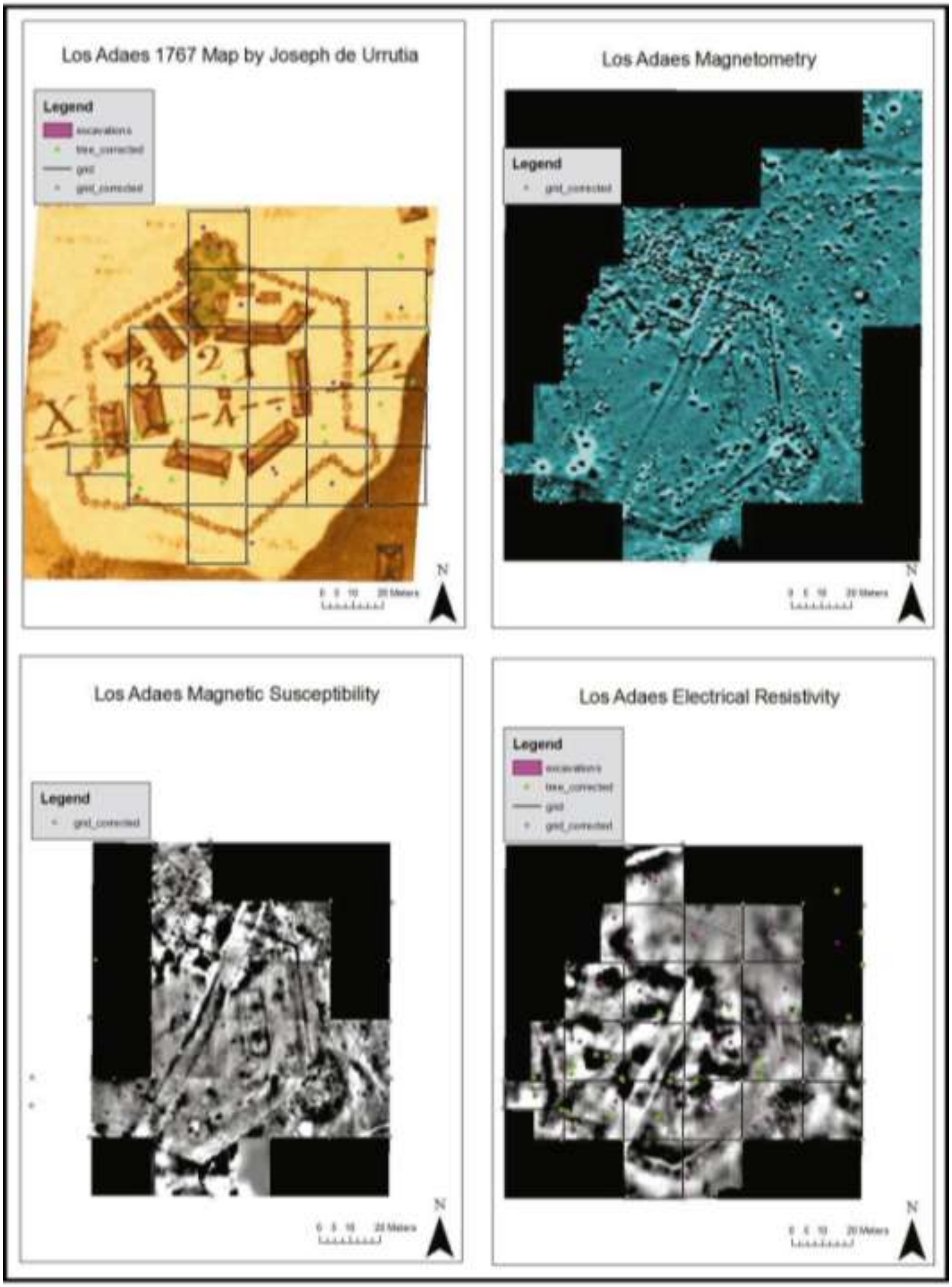


Figure 5-41. Configuration of the southern palisade as shown in the 1767 map, magnetic gradient, magnetic susceptibility, and electrical resistance data.

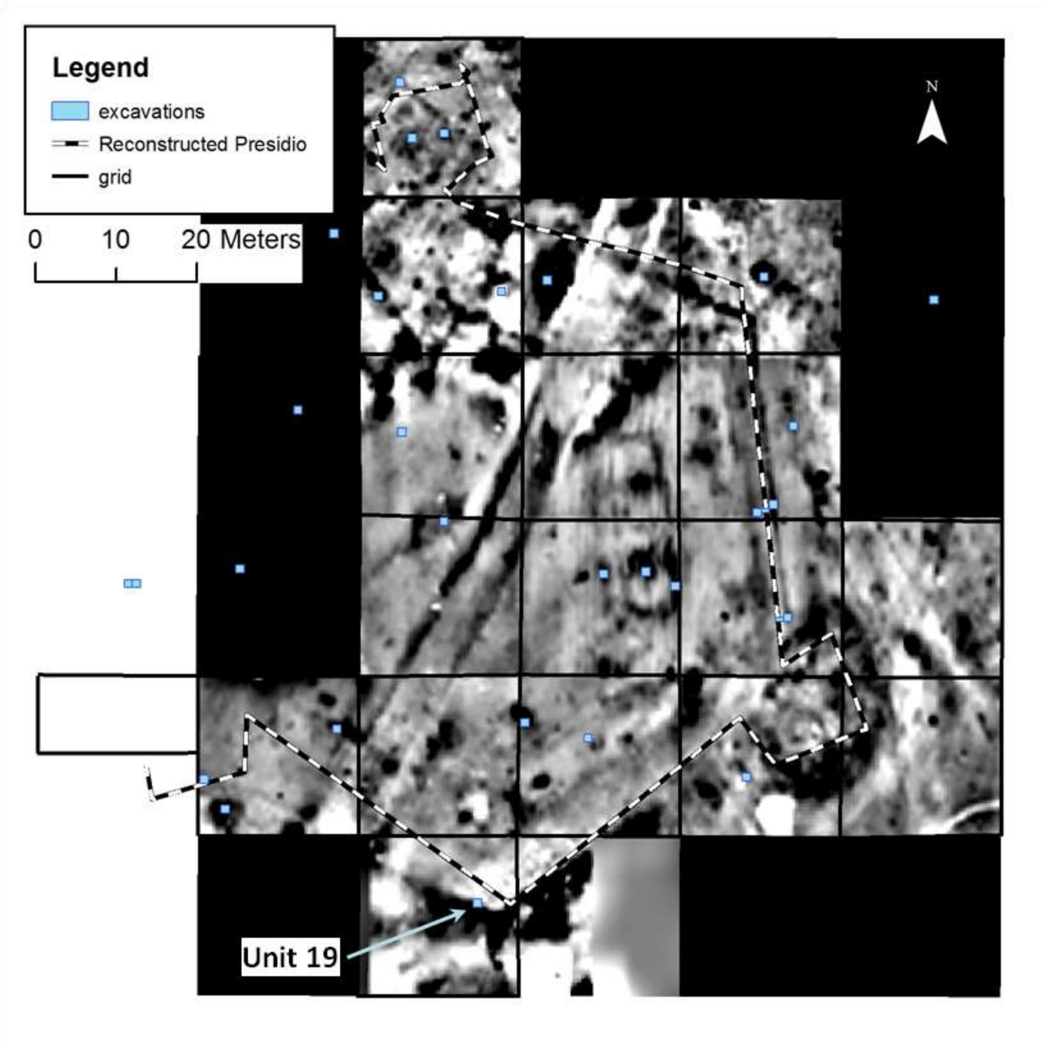


Figure 5-42. Magnetic susceptibility image showing the discrepancy between the actual and reconstructed southern presidio. The presidio is clearly visible in the magnetic susceptibility data and diverges from the reconstructed presidio (marked by horizontal wooden beams on the ground surface) in the southwest near unit 19. Unit 19 confirmed the presence of the presidio in the location south of the reconstructed one.

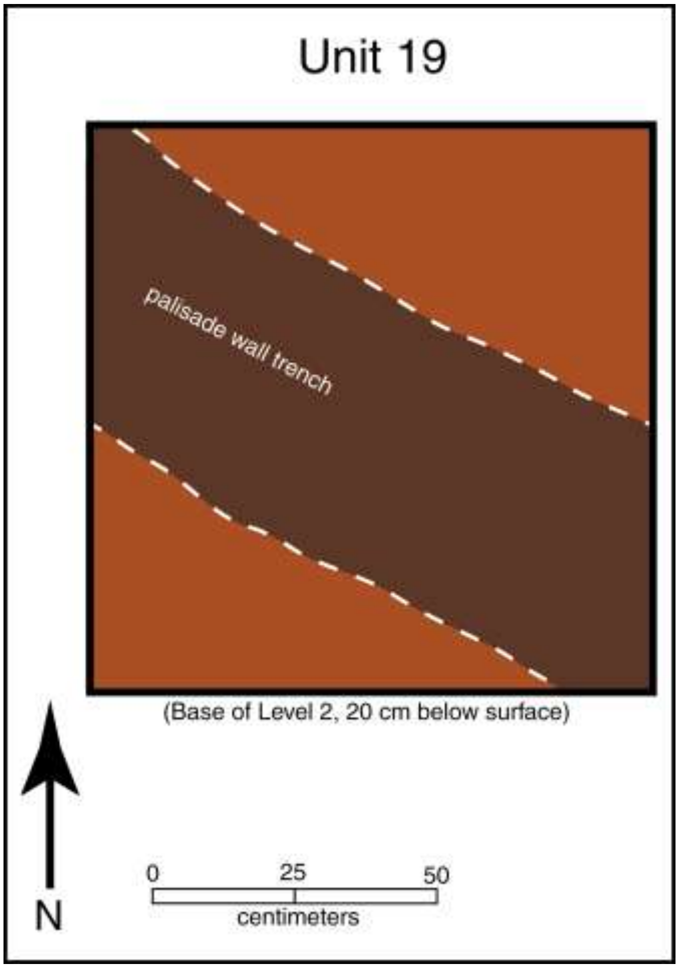


Figure 5-43. Unit 19 verified the interpretation that a linear anomaly represented the southern palisade.

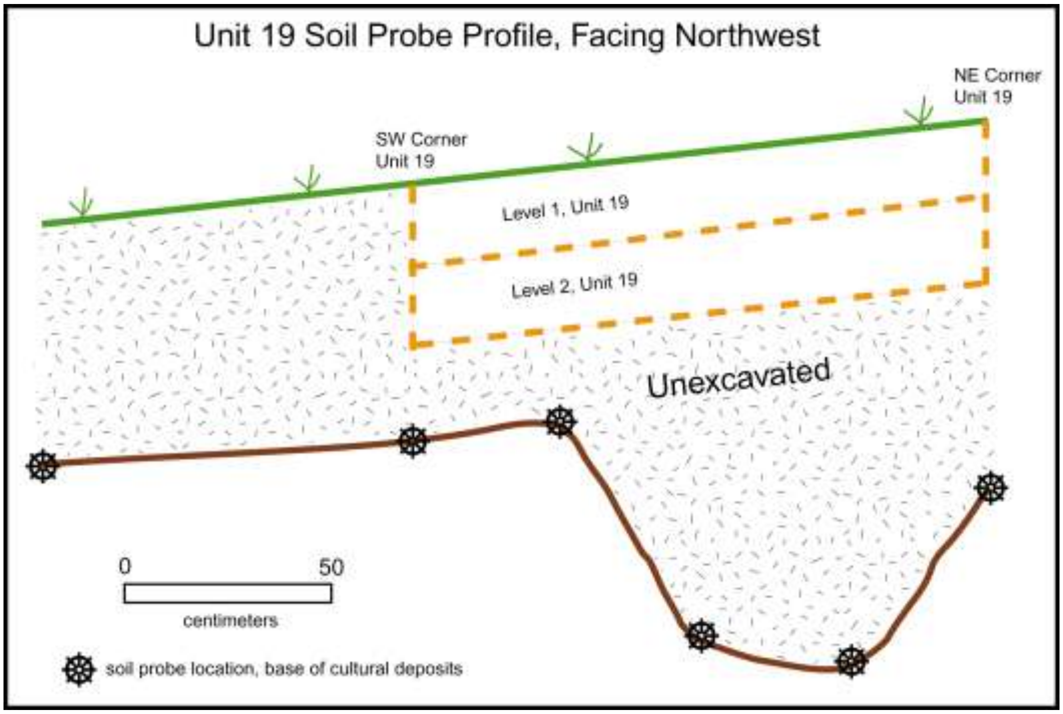


Figure 5-44. Profile map based on soil probes showing the wall trench associated with the southern palisade.

Region J—Subaltern's Quarters, Units 20 and 21

The 1720 architect's plan designates the barracks building closest to the gate as the *quarteles de subalternos*, or subaltern's quarters. A subaltern was any rank lower than a captain, and since the only ranks present at Los Adaes below the governor were lieutenant, sergeant, and corporal, it is likely that the barracks in question housed some or all of those individuals. The 1720 plan shows a gate on the southern wall, but the 1767 map shows it on the western wall. Since the subalterns' barracks was nearest the gate on the 1720 map, the same may be true for the 1767 map (Figure 5-45). A faint linear magnetic anomaly (Figure 5-46) was interpreted as a wall associated with either the subaltern's quarters or the palisade. Unit 20 was excavated to ground test this interpretation.

Unit 20 (Figure 5-47) was excavated to a depth of 20 cm. A north-south linear band of darker soil was observed along the west wall at that depth. It was necessary to excavate Unit 21 off the western end of Unit 20 to determine whether the apparent wall was associated with the palisade or a barracks (Figure 5-47). A linear feature was clearly visible in Unit 21 at 10 cm bs, and was excavated as a distinct feature in Level 2. It was no longer visible at 20 cm bs in the south part of Unit 21, but soil probes indicated that the trench continued to 25 cm bs in the north part of Unit 21. The soil in Unit 20 outside the trench was compacted sandy clay. The soil in Unit 20, Level 2 outside the trench feature was compacted clay that, when excavated, came out in clods and contained very few artifacts and very little ironstone concretions. It was interpreted as clay that had been brought in as packing for outer wall support.

The linear trench observed in Units 20 and 21 is much too shallow to be the western palisade. It is more likely that this small trench is related to the barracks depicted on the 1767 map that is closest to the gate. It may be a wall trench feature, although no post holes or post molds were observed. Soil probes near the eastern walls of Units 20 and 21 detected white silt/silty loam—a natural soil horizon—at 20 and 25 cm bs, respectively. A soil probe 2 meters west of Unit 21 revealed the white silt/silty loam horizon at 25 cm bs. No indications of the western palisade wall trench were identified with soil probes.

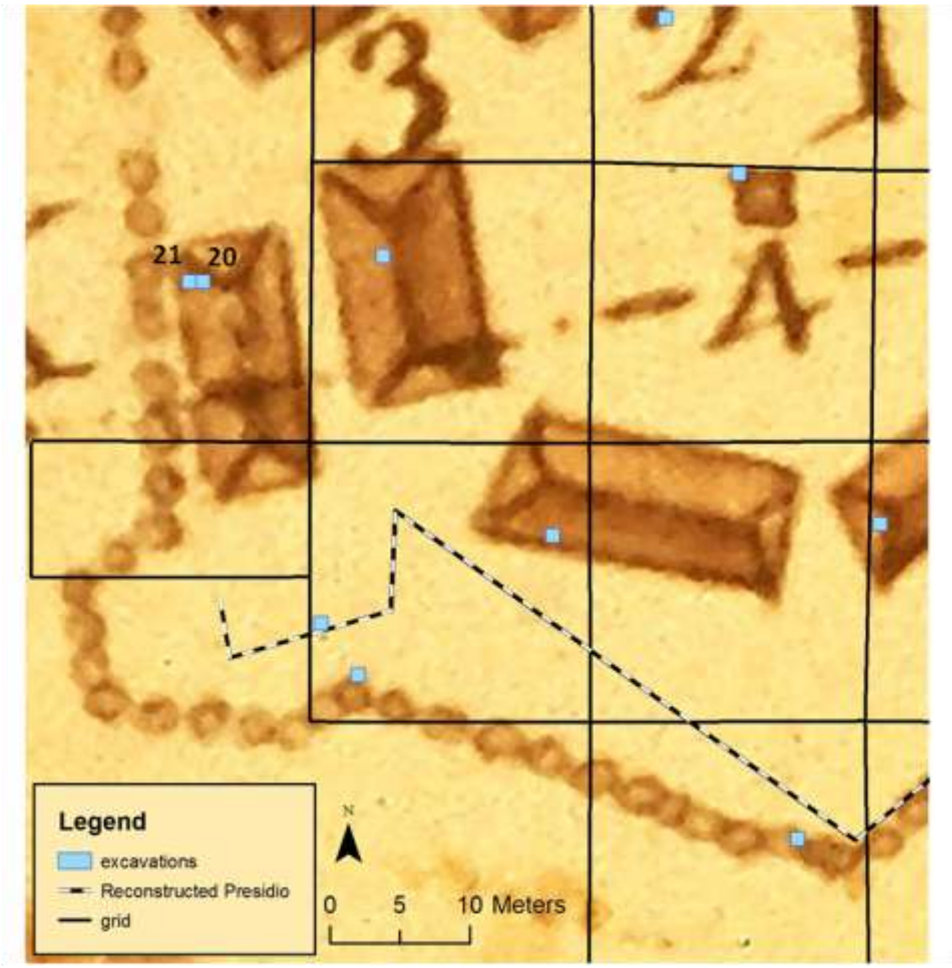


Figure 5-45. Portion of the 1767 map showing the location of units 20 and 21near the west wall of a barracks.

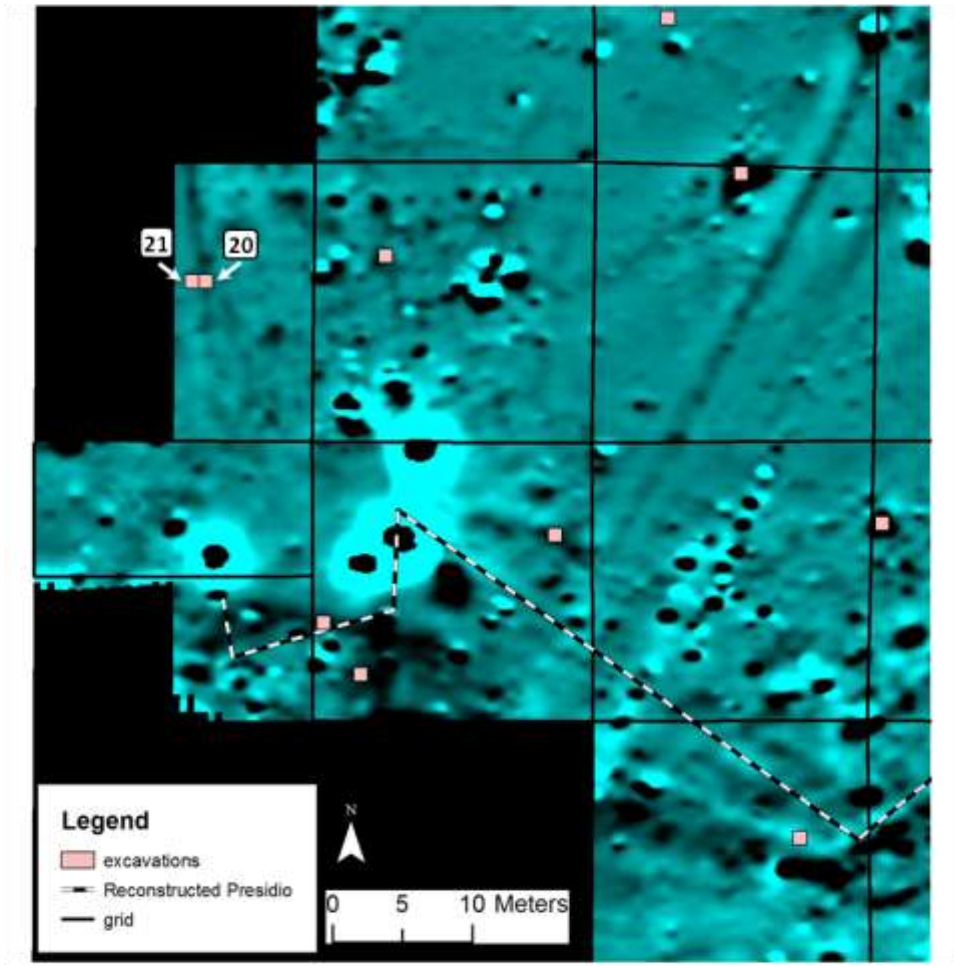


Figure 5-46. Magnetic gradient image showing the location of units 20 and 21 targeting the west wall of a barracks.

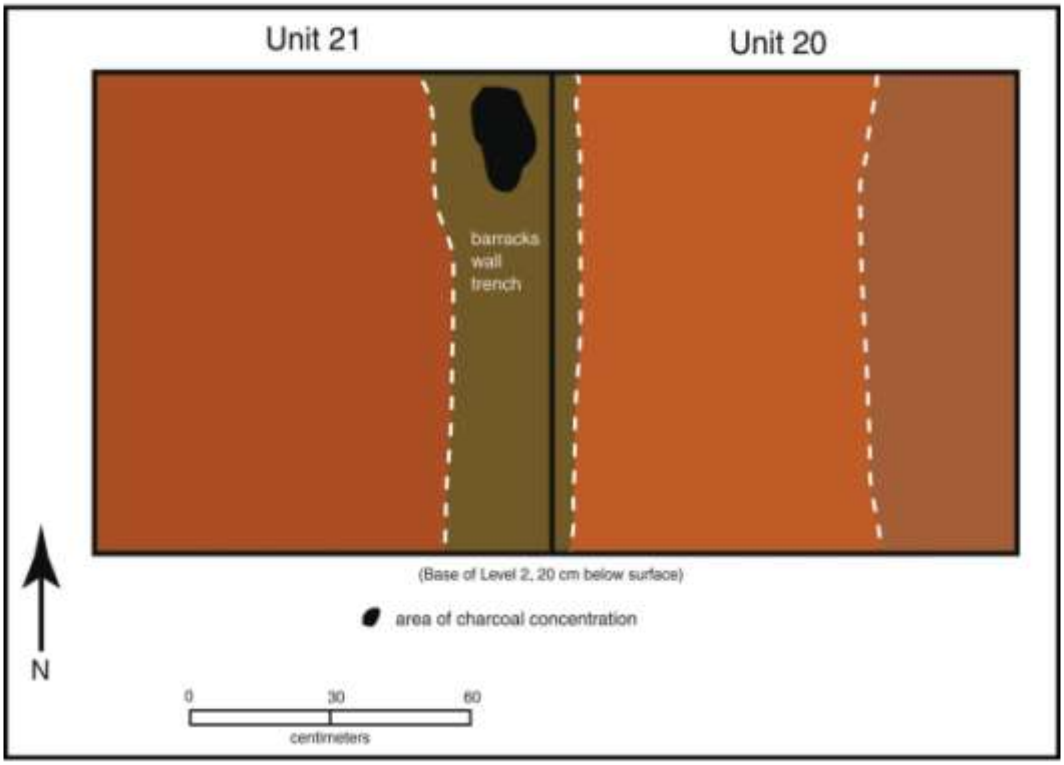


Figure 5-47. Units 20 and 21 showing a linear feature verified to be a barracks wall.

Summary of Ground Truthing Results

Table 5-3 summarizes the interpretations of the geophysical anomalies and results of ground truthing. Eighteen units totaling 15 m^2 were excavated. Five of the target anomalies initially selected for ground truthing were not investigated in order to stay within the 15 m^2 maximum specified by our permit for excavation granted by the Louisiana Division of Archaeology and to investigate several locations that Avery felt were particularly important. Interpretations of eleven (73.3%) of the 15 distinct targeted anomalies were confirmed. One other was partially confirmed (a linear feature was found where a structure had been predicted, but the feature was faint and discontinuous), and acceptance of that result would bring the success rate for interpretations to 80%. Based on our experience, this is higher than would be achieved for many sites, particularly prehistoric sites with no apparent architectural remains. Los Adaes exhibits a distinctive settlement plan, and anomalies associated with barracks walls and the palisades were not difficult to interpret. This should not lead to a disregard for the value of geophysics. In nearly all cases, the Los Adaes geophysical data allowed very small excavation units to be located directly on the suspected features. Without geophysics, far more excavation would be required to collect similar information about the site. Proof of this is seen in the large number of units excavated in previous efforts to locate features depicted in the historic maps (Gregory et al. 2004). Our only real disappointment was the failure to detect the western palisade. We are confident that could have been done had it not been for dense trees that precluded geophysical survey of the western-most portions of the fort.

In terms of ground truthing methods, our reliance on the excavation of very small (1x1 m) excavation units supplemented by soil cores was highly effective. Our only error was conducting the excavations at a time when the ground was extremely dry. Had the soil been much drier, we might not have been able to use soil coring at all, and that would have required either the excavation of more units (which was not an option given our permit and project funds) or the acceptance of less information about feature dimensions, particularly maximum depth. Where soil probes can be excavated and color or texture differences associated with feature fill can be detected, they can dramatically reduce the cost and/or increase the information return of ground truthing excavations.

It was unfortunate that the ground truthing could not have been conducted during the NPS course, allowing more participants to observe it. That would have detracted from the participant’s ability to focus on the methods and instruments that are central to the integrated multi-sensor approach. Use of the sensors represented new information for most of the NPS participants, whereas most or all of them were experienced in archaeological excavation.

Table 5-3. Summary of anomaly interpretations and results of ground truthing.

Region	Unit	Interpretation	Ground truthing results
A	1	Structure wall near SW bastion	Partially confirmed; Linear feature present, uncertain if it is associated with a structure
A	2	Structure within or near SW bastion	Rejected; Mounded area associated with bastion, not a discrete structure
A	3	Feature inside a barracks structure	Confirmed; Feature comprised of mounded debris, not a facility
B	4	Feature in/on barracks floor	Confirmed; collapsed earth oven or brazier platform
B	5	Feature in or near barracks	Rejected; previous excavation units
C	6	Entry in palisade or old excavation unit	Confirmed; old excavation unit
D	7	Western edge of a barracks structure, possibly a porch	Confirmed; a prepared surface, possibly associated with the expected porch
D	8	Feature in/on barracks floor	Confirmed by soil cores to be a feature similar to Unit 4
D	9	Eastern wall of barracks	Confirmed; wall trench for barracks wall
E	10	Barracks	Rejected; no evidence of a linear feature
E	10A	No prediction	NA; prepared surface flanking palisade wall trench
E	11	Eastern palisade	Confirmed; wall trench with prepared surface on both sides
E	12	Eastern Moat	Confirmed; 75-cm deep deposits including gley soil.
	13	Not excavated	
	14	Not excavated	
	15	Not excavated	
	16	Not excavated	
H	17	Discrete feature, type uncertain	Confirmed; Deposit of rich midden
	18	Not excavated	
I	19	Southern palisade	Confirmed; palisade wall trench
J	20	Wall of barracks or palisade	Confirmed; barracks wall
J	21	Wall of barracks or palisade	Confirmed; barracks wall

5.5 SAMPLING PROTOCOL

The portion of the Los Adaes site that is accessible for geophysical data collection measures approximately 200 m (NE-SW) by 120 m (NW-SE), with an area of approximately 2.5 hectares. Covering the entire area would be desirable from a research perspective but was not necessary for purposes of this project. Our original goal was to collect high resolution GPR, conductivity, magnetic susceptibility, electrical resistance, and magnetic gradiometry data across an area of .5 hectare for a 20% sample. We exceeded this goal by surveying .68 hectare with all instruments, and significantly more area with some but not all instruments. Table 5-4 lists the area covered by each instrument, and this is shown graphically in Figure 5-7. The area surveyed was based on the historic maps, and successfully conveyed the fort's distinctive configuration.

Table 5-4. Area covered by geophysical survey at Los Adaes

Method	*Area Survey (square meters)*
Magnetometry	13,200
Electromagnetic Induction (magnetic susceptibility and conductivity)	7,200
Resistivity	8,800
Ground-penetrating Radar	6,800

5.6 SAMPLING RESULTS

This project's demonstration and validation component included the following steps: a) a beta-test of *ArchaeoFusion*; b) a multi-sensor survey of a complex archaeological site, c) processing and integration of the data using *ArchaeoFusion*, d) predictions about the nature of subsurface features, and e) an independent evaluation of those predictions by means of small-scale, carefully targeted excavations. All sampling results for these steps are reported in previous sections of this report. Table 5-5 lists the locations of all sampling results for each step of the demonstration.

Table 5-5. Locations of all Sampling Results

Demonstration Step	*Location (Section Number)*
ArchaeoFusion beta test	5.4.1
Multisensor data collection	5.4.2
Data processing and integration using *ArchaeoFusion*	5.4.3
Data interpretation and prediction of archaeological features using *ArchaeoFusion*	5.4.4
Verification of interpretations by ground truth	5.4.5

6.0 PERFORMANCE ASSESSMENT

As described in Section 3, the Performance Assessment for this project was completed by two separate assessments: Assessment 1 and Assessment 2. In this section, we summarize the data analysis conducted in support of the assessment of performance objectives. Although this performance assessment focuses primarily on the quantitative evaluation of *ArchaeoFusion*, an equally important effort and a major outcome of this project was the multisensor geophysical survey and ground truthing at Los Adaes, as described in Section 5.4.2. The demonstration of the multisensor geophysical approach to archaeological site evaluation is a substantial contribution to the field of archaeology, but assessment of this contribution is mostly qualitative. Only the final phase of the Los Adaes geophysical survey effort, ground truthing, can be evaluated quantitatively as described for Performance Objective 9 (Section 6.9).

6.1 PERFORMANCE OBJECTIVES

Each Performance Objective is listed below followed by a summary of the results data for Assessments 1 and 2, analysis for Assessment 1, and when necessary for Assessment 2), and conclusions based on both assessments. Details about planned analysis, metrics, and criteria for success as planned for Assessment 1 and survey questions used for Assessment 2 are given in Section 3.

6.2 OBJECTIVE 1

Non-integrated multi-sensor surveys provide more useful information than single sensor surveys.

Assessment 1 Results Data: Tables 6-1 through 6-4 list the results from each participant.

Table 6-1. Participant 1 results

Data type	N anom.	N feature anom	% increase when all 5 datasets used	N anom. in this dataset only	% decrease when single dataset anomalies are deleted
Magnetic	18	3	278	4	78
Mag. Suscept.	20	13	240	6	70
Resistance	7	3	871	2	71
Conductivity	6	2	1033	0	100
GPR	40	4	70	15	63
Combined (unique loci)	68	15	-	27	60

Table 6-2. Participant 2 results:

Data type	N anom	N feature anom	% increase when all 5 datasets used	N anom in this dataset only	% decrease when single dataset anomalies are deleted
Magnetic	9	3	0	7	22
Mag. Suscept.	4	2	125	2	50
Resistance	4	4	125	3	25
Conductivity	3	3	200	0	100
GPR	3	3	200	2	33
Combined (unique loci)	9	5	-	14?	56% increase?

Table 6-3. Participant 3 results:

Data type	N anom	N feature anom	% increase when all 5 datasets used	N anom in this dataset only	% decrease when single dataset anomalies are deleted
Magnetic	5	3	220	3	40
Mag. Suscept.	2	2	700	0	100
Resistance	4	2	300	2	50
Conductivity	4	3	300	2	50
GPR	6	2	167	6	0
Combined (unique loci)	16	6	-	13?	19?

Table 6-4. Participant 4 results.

Data type	N anom	N feature anom	% increase when all 5 datasets used	N anom in this dataset only	% decrease when single dataset anomalies are deleted
Magnetic	39	26	41	12	69
Mag. Suscept.	18	4	206	5	72
Resistance	10	4	450	3	70
Conductivity	13	8	323	4	69
GPR	51	6	8	37	27
Combined (unique loci)	55	38	-	61?	11% increase?

Assessment 2 Results Data: 100% of Assessment 2 participants agreed that, in regards to archaeological geophysics in general (regardless of software): multiple surveys, even when not integrated, provide more useful information than single sensor surveys.

Assessment 1 Analysis

(a) In the majority of cases, the total number of anomalies identified in five combined single sensor datasets was at least 50% greater than the number identified in any single dataset. The exceptions to this are the magnetometry data interpreted by participant 2, and the magnetometry and GPR data interpreted by participant 4. This amounts to an 85% success rate, or 17 out of 20 successful cases.

(b) In the majority of cases, the total number of feature anomalies identified in five combined single sensor datasets was at least 50% greater than the number identified in any single dataset. Exceptions include the magnetic susceptibility data interpreted by participant 1, everything except the magnetic susceptibility data interpreted by participant 2, and the magnetic data interpreted by participant 4. This amounts to a 70% success rate, or 14 out of 20 successful cases.

(c) Deletion of all anomalies that appear in only one of the five single sensor datasets increased the ratio of feature anomalies to anomalies by at least 50% in all cases. This amounts to a 100% success rate.

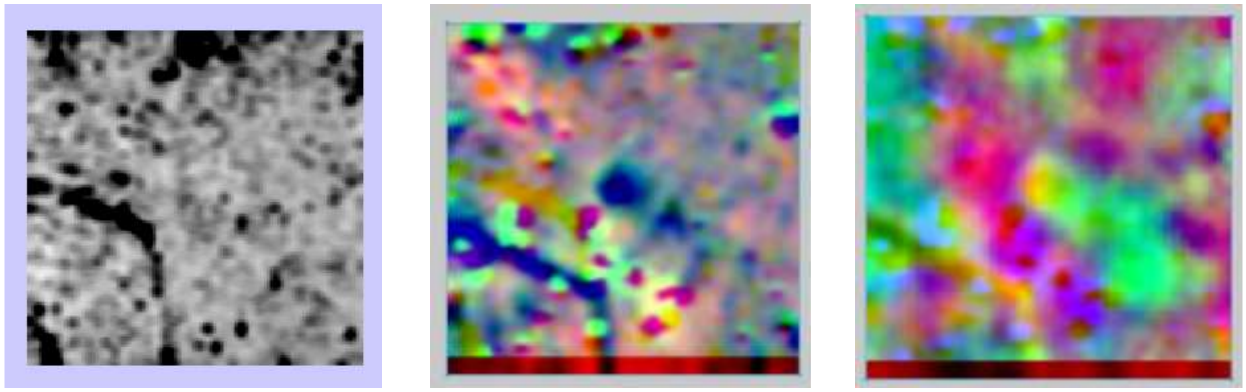
Conclusions

Although there are exceptions, Assessment 1 results show that non-integrated multi-sensor surveys provide more useful information than single sensor surveys. In addition, Assessment 2 shows unanimous agreement to statement 1 among 14 respondents that "…multiple surveys, even when not integrated, provide more useful information than single sensor surveys."

6.3 Objective 2

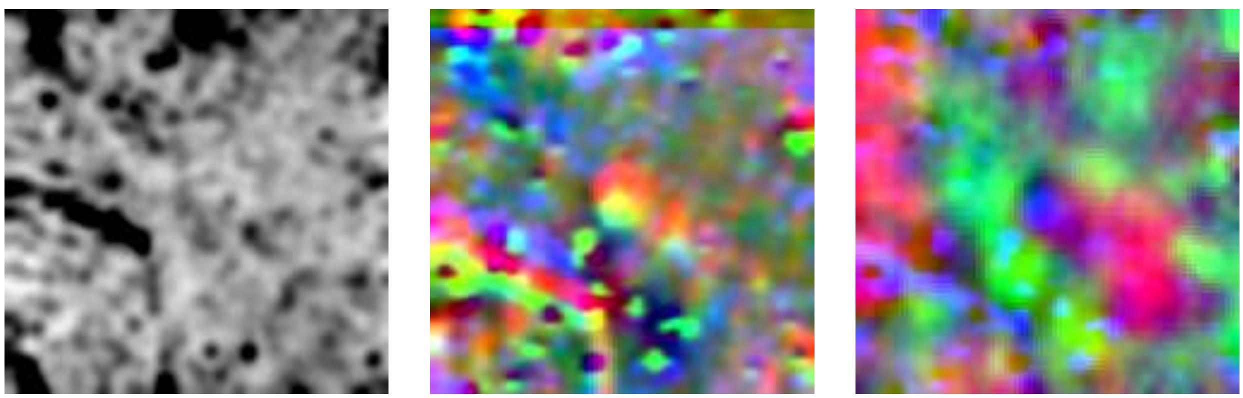
Data integration increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets.

Assessment 1 Results Data: Integrated data for each participant are shown in figures 6-1 through 6-4.



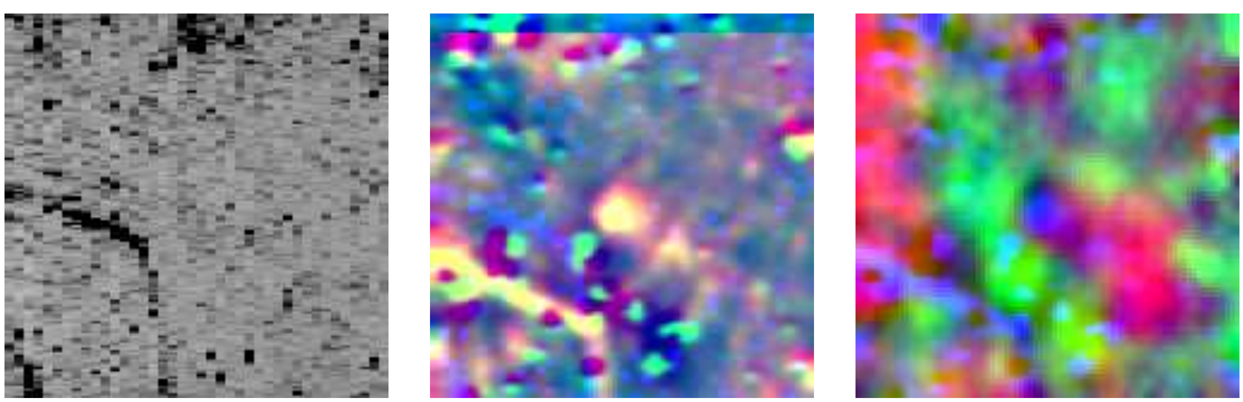
GPR PCA Fusion | Translucent Overlay | Sum Math Fusion

Figure 6-1. Fusion results for Participant 1.



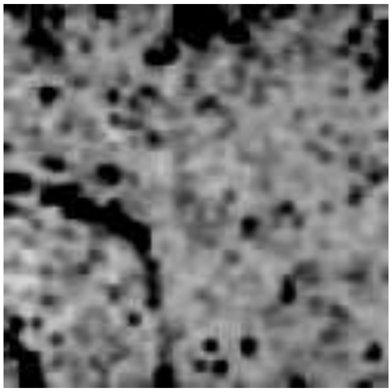
GPR PCA Fusion | Translucent Overlay | Sum Math Fusion

Figure 6-2. Fusion results for Participant 2.

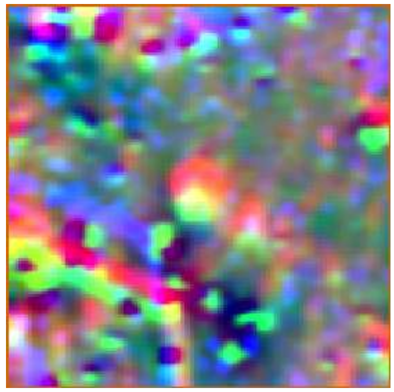


GPR PCA Fusion | Translucent Overlay | Sum Math Fusion

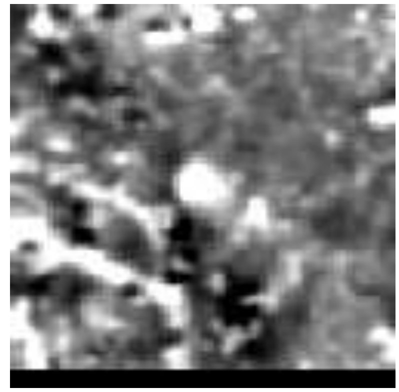
Figure 6-3. Fusion results for Participant 3.



GPR PCA Fusion



Translucent Overlay



Sum Math Fusion

Figure 6-4. Fusion results for Participant 4.

Assessment 1 participants were asked to answer the following multiple choice questions with reference to their experience from the exercises in the guided tutorials:

1) Integrating multiple datasets using *ArchaeoMapper* increased my ability to detect feature anomalies.
   a Very true
   b Somewhat true
   c Neither true nor false
   d Somewhat false
   e Very false

2) Integrating multiple datasets using *ArchaeoMapper* increased my ability to determine one or more characteristics of the feature anomalies (e.g., feature size, shape, depth, relative location to other anomalies, whether it was burned, presence of rock concentrations, etc.).
   a Very true
   b Somewhat true
   c Neither true nor false
   d Somewhat false
   e Very false

Table 6-5 summarizes the responses to these questions.

Table 6-5. Responses to questions for performance objective 2

	Participant 1	Participant 2	Participant 3	Participant 4
Question 1	very true	neither true nor false	very true	very true
Question 2	very true	somewhat true	very true	very true

Assessment 2 Results Data: 100% of Assessment 2 participants agree that, in regards to archaeological geophysics in general (regardless of software), data integration increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets

Assessment 1 Analysis

(a) Assessment 1 participants did not identify anomalies in the fused data, so this part of the analysis cannot be completed. The results (Figures 6-1 through 6-4) do show, however, consistently similar results from all participants, with only minor differences due to choice of color palettes and smoothing algorithms.

(b) 75% of the participants agreed that integrating multiple datasets using *ArchaeoFusion* increased their ability to detect feature anomalies (Table 6-5).

(c) 100% of the participants agreed that integrating multiple datasets using *ArchaeoFusion* increased their ability to determine one or more characteristics of feature anomalies.

Conclusions

The results of Assessment 1 generally support the hypothesis that data integration increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets. This is probably a fair assessment of the general feeling about data integration among users of archaeological geophysics. Many agree that it is useful and the advantage is in the ability to clearly show multiple datasets together to realize interrelationships between them. Yet, a small percentage still argue that the same information can be gleaned from non-integrated data using older, tried and true methods of data interpretation.

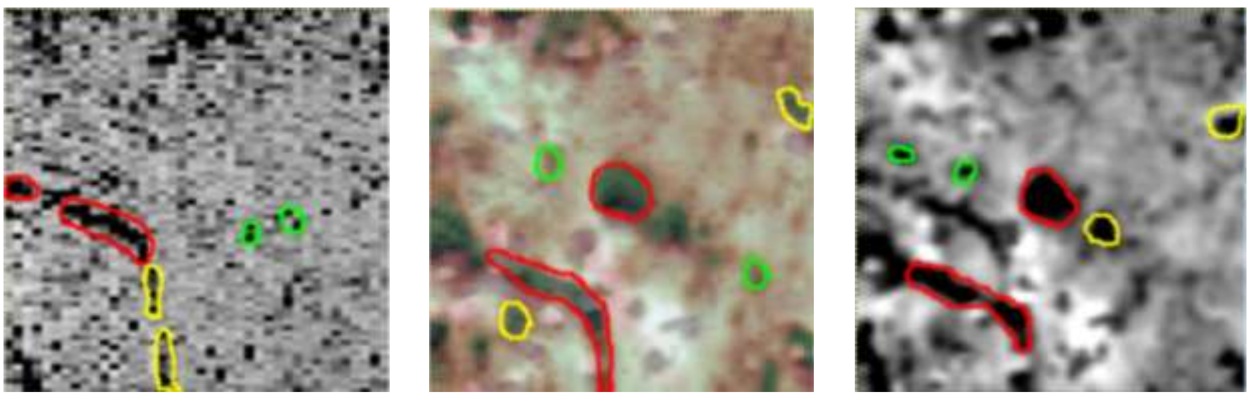
Assessment 2 shows unanimous agreement to statement 2 that "data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc) increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets."

6.4 OBJECTIVE 3

ArchaeoFusion allows all users to effectively integrate data from multiple sensors.

Assessment 1 Results Data: Figure 6-5 shows the three different data integrations performed by the project team's *ArchaeoFusion* expert for this evaluation. Principle Components Analysis of GPR slices and the sum mathematical fusion were done using IDRISI (Clark Labs). It took

approximately 90 minutes to complete these tasks, which entailed processing and slicing GPR data in Radan, gridding slices in Surfer, then importing into IDRISI to create the GPR PCA Fusion. An additional 30 minutes were required to convert the EMI data (conductivity and magnetic susceptibility) using DAT38 software, then import into ArchaeoSurveyor for 2D processing, then export to Surfer to reformat, and finally into IDRISI for the Sum Math Fusion. Next, 20 minutes was needed to process the magnetometry data in ArchaeoSurveyor, convert formatting in Surfer, and then bring into IDRISI. A translucent overlay was created using GIMP (freeware similar to Adobe Photoshop), which took an additional 20 minutes. In total, it took approximately 160 minutes to create the three fusion products shown in Figure 6-5. In contrast, the same results can be achieved in approximately 60 minutes using *ArchaeoFusion*, mainly because the data do not need to be imported, exported, or reformatted in other software environments. This is an improvement in time efficiency of 167%. Each of the fusion results has two control anomalies in each of the three categories (subtle, intermediate, and robust). Assessment 1 participant fusion results are shown in Figures 6-1 through 6-4.



GPR PCA Fusion | Translucent Overlay | Sum Math Fusion

Figure 6-5. Fusion results produced by the project team's *ArchaeoFusion* expert using other software (not *ArchaeoFusion*), with control anomalies marked. Key: red = robust anomalies; yellow = intermediate anomalies; green = subtle anomalies.

Assessment 2 Results Data: 92% of Assessment 2 participants agree that *ArchaeoFusion* allows users to effectively integrate data from multiple sensors.

Assessment 1 Analysis: Clearly, 100% of the anomalies identified in the control data (Figure 6-5) are visible in the fusion results produced by participants using *ArchaeoFusion*. In fact, the GPR PCA fusion and translucent overlay results produced by the participants using *ArchaeoFusion* show the control anomalies more clearly and robustly.

Assessment 2 Analysis: Assessment 2 showed that 12 out of 13 respondents agree with statement 3 that "*ArchaeoFusion* allows users to effectively integrate data from multiple sensors…" Respondent 10 marked "neutral" to this survey question and in comments wrote: "I used *ArchaeoFusion* briefly, but ran into problems trying to process data (getting errors from the Matlab substrate). …aside from the problems…, I found the software fairly easy to use." This

problem was likely due to incompatible hardware. There were several other comments about data integration functionality in *ArchaeoFusion*:

> The main benefit of *ArchaeoFusion* is that it gives the user the ability to integrate data from multiple geophysical data types using a straight-forward and user-friendly interface. Before this product, I was using proprietary software, Surfer, IDRISI, and other GIS software to open, transform, and analyze data from each type of sensor (GPR, gradiometer, resistance) separately. I would then have to use GIS software to assemble the data into a single map, having to do some additional "tweaking." In the few months I have been using *ArchaeoFusion*, I have saved dozens of hours in analysis because the program performs all of these operations simultaneously. It has become an invaluable part of my research, and I will recommend it to my colleagues. (Respondent 4)

> I especially like how easy it is to overlay multiple surveys. (Respondent 8)

> This program…doesn't just make it simpler to do more with different data sets: after data are processed, the available options actually encourage the user to try out different ways of combining data sets to see how they compare. …Traditionally, I have resorted to simple image overlay options in GIS or graphics packages in order to compare and analyze my data. I then produced separate interpretations for each data set, before overlaying these for comparison. Therefore the option to directly compare data beyond simple overlays, using mathematical and statistical combinations, opens up new avenues for exploring and better understanding the data I've collected. It is also extremely welcome to have one package that can cope with processing data from a variety of sources. (Respondent 12)

> Excellent to have a single platform for integrating the most commonly used sensors in archaeological geophysics. Also a very significant contribution is the procedures for combining/fusing data. More development of these methods (in archaeology generally as well as in *ArchaeoFusion* specifically) would be very welcome across the community. (Respondent 13)

> I found *ArchaeoFusion* very useful as I was able to much more effectively analyze my project data that I had previously been unable to easily compare using more conventional means. (Respondent 14)

These statements strongly support one of the primary goals of this project – to streamline archaeogeophysical data processing and integration by assembling a single, user-friendly software tool.

Conclusions: Assessments 1 and 2 results strongly support the idea that *ArchaeoFusion* allows all users to effectively integrate data from multiple sensors. The integrated results produced by the project team using alternative software are not as good as those produced by *ArchaeoFusion* and took longer to produce, and 92% of participants in Assessment 2 agree that *ArchaeoFusion* allows them to effectively integrate data. This suggests that *ArchaeoFusion* is a superior tool for integrating geophysical data from multiple sensors.

6.5 Objective 4

Data processing using *ArchaeoFusion* is faster and easier than processing using COTS (commercial off-the-shelf) software.

Assessment 1 Results Data: Table 6-6 shows the times taken for Assessment 1 participants to process the provided geophysical data using COTS software and using *ArchaeoFusion*.

Table 6-6. Time taken by participants to process the data using their choice of COTS software versus time taken using *ArchaeoFusion*.

	Participant 1	Participant 2	Participant 3	Participant 4
Time using COTS software	55 min.	not reported	3 hours	not reported
Time using *ArchaeoFusion*	31 min.	not reported	8 hours	not reported

Assessment 2 Results Data: 61% of Assessment 2 respondents agreed that data processing using *ArchaeoFusion* is faster and easier than processing using other COTS (commercial off-the-shelf) software.

Assessment 1 Analysis: There is not enough data from Assessment 1 to formally evaluate this performance objective for two reasons. First, some of the participants did not have time to complete the entire evaluation, and did not report all results. Second, the low numbers of participants meant that results could not be shared between pairs of participants, which was part of the original test design. The data that we do have neither supports nor refutes the idea that processing data in *ArchaeoFusion* is faster and easier than with other software. Assessment 1 participant 1 increased time efficiency by 44 percent, while participant 3 decreased time efficiency by 167 percent. As a comparison, use of *ArchaeoFusion* to produce the fusion results in Figure 6-5 resulted in a 167% increase in time efficiency. The discrepancy in these findings results from the vast differences in the type of data processed by the Assessment 1 participants and the project team's *ArchaeoFusion* expert and differences in experience level and ability to learn new software.

Assessment 2 Analysis: Comments from Assessment 2 respondents 6 and 8, who marked "neutral" to statement 7, show that they are new users of archaeogeophysics and may not have used other software enough to make an informed comparison. Respondent 1, who marked neutral, is the only user who completed the original assessment (as Participant 3). It shows, however, that despite his results in the original survey, he does not disagree with Statement 7. Finally, respondent 7, who disagreed with statement 7, is an experienced user of archaeogeophysics, but unfortunately had much difficulty getting *ArchaeoFusion* to function properly. Still, this user remarked that "*ArchaeoFusion* could potentially be an excellent tool, and I would be interested in trying it again if it can be brought to a useful level of functionality." The errors encountered by respondent 7 were due to hardware incompatibility.

Conclusions: Results from the original assessment neither support nor dispute the hypothesis that *ArchaeoFusion* decreases time needed to process geophysical data. The main reason for this could be that users had little or no prior experience with *ArchaeoFusion*, so it took them a long time to process the data while simultaneously learning the software. In fact, the project team spent many hours working with Participant 3 on the phone and through email. Many of the problems were resolved this way, but some were not and likely frustrated the user and added hours to processing time. Assessment 2 shows that *ArchaeoFusion* does decrease the time needed to process geophysical data, although it is disappointing that the level of agreement was

only 67%. This may be due to user's comfort level with existing software, some of which has been in use for decades with very little change, versus a new and more multifaceted software (*ArchaeoFusion*).

6.6 Objective 5

Data from all major sensor types can be adequately processed using only *ArchaeoFusion.*

Assessment 1 Results Data: None of the participants completed this part of the original evaluation.

Assessment 2 Results Data: 46% of Assessment 2 participants agree that data from all major sensor types can be adequately processed using *ArchaeoFusion* alone.

Assessment 1 Analysis: No data are available for analysis.

Assessment 2 Analysis: Nearly half (6 out of 13) of all respondents agreed with statement 4 that "data from all major sensor types can be adequately processed using *ArchaeoFusion* alone." Three respondents marked "neutral" and four disagreed. User comments reveal two common problems that led to marking "disagree" for this statement. First, two out of four respondents (7 and 12) encountered technical difficulties that resulted in errors and limited the functionality of the software. While *ArchaeoFusion* has been extensively tested in-house and externally by a small beta test group, these errors are new and very difficult to solve without more detailed feedback from those users, which has been requested but very little received. We continue to work to resolve these problems.

The second reason is related to *ArchaeoFusion*'s GPR processing capabilities. Respondent 2 did not comment in the survey, but through email and in person has expressed his disappointment with the GPR capabilities of *ArchaeoFusion*. Respondent 13 also disagreed with statement 4, stating that "certain processing procedures (especially for GPR) can be done more effectively in dedicated software packages." In addition, some users who did not disagree with statement 4 still commented on the GPR capabilities. Respondent 1, who also participated in the original survey as Participant 3, is an advanced GPR user and most of the problems he encountered were related to GPR processing. Respondent 4 marked "Agree" to statement 4, but still had the following to say on this subject:

> The main shortcoming in the program is the GPR analytical module. This module is functional and it *does perform the necessary operations* (emphasis added), but it is much more cumbersome to use than software like GPR-Slice. Importing GPR data is much more involved than the other sensors types, and I found myself a bit confused at the various choices one has when importing. (Respondent 4)

While advanced GPR processing was not a part of the original design of *ArchaeoFusion*, the survey shows that improved GPR functionality and usability would satisfy many users and make it a more well-rounded and useful product. It is no surprise that this is the case, since GPR data are much more complex than other data types. Some users are looking for simplified data processing because other software packages are too complex for beginning users. Other users require expert functionality, and this is very hard to provide without a complex interface. As noted by Respondent 4, *ArchaeoFusion* does perform the necessary operations for GPR, but

clearly many users would like to see improvements. Future improvements to *ArchaeoFusion* will likely include a more user-friendly GPR module with more advanced options.

Conclusions

It appears from Assessment 2 comments that *ArchaeoFusion* is capable of processing all of the main types of geophysical data, but for many users it is not adequate for their level of need for GPR processing. We interpret this to mean that the software satisfies the needs of this project, but does not provide enough sophisticated processing capabilities for advanced GPR users.

6.7 Objective 6

ArchaeoFusion preserves data resolution.

Assessment 1 Results Data: By nature of its design, *ArchaeoFusion* preserves data resolution. This was true for all Assessment 1 participants.

Assessment 2 Results Data: 100% of users agree that *ArchaeoFusion* preserves data resolution.

Analysis: *ArchaeoFusion* is designed so that data resolution is never lost. Every operation is reversible, including operations that resample the data. As a result, the original data is never directly modified, and is always saved as part of the project. *ArchaeoFusion* saved the original raw data and the operations stack separately.

Conclusions: *ArchaeoFusion* preserves data resolution, by nature of its design, and Assessments 1 and 2 support this claim 100%.

6.8 Objective 7

ArchaeoFusion reduces the time needed and increases the quality and consistency of metadata for geophysical data.

Assessment 1 Results Data: None of the student participants completed this part of Assessment 1, so we do not have any data to formally evaluate this objective.

Assessment 2 Results Data: 54% of Assessment 2 respondents agree that, in comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers (i.e. GPR, EMI, magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data.

Assessment 1 Analysis: No data are available for analysis.

Assessment 2 Analysis: More than half (54%) of respondents agreed that *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. The remaining 46% of respondents marked “neutral” to this statement. No single respondent disagreed. While none of the respondents addressed this issue in their comments, it is clear that most of the respondents who marked “neutral” do not have experience with using multiple software packages to process and integrate geophysical data from different instruments and manufacturers, and so could not honestly agree with the statement. For example, the following comments are from respondents who marked “neutral”:

> I represent a local community based archaeological group. I use *ArchaeoFusion* to process my basic earth resistance data and hope to combine it with our aerial data. I find *ArchaeoFusion* very useful, but do not think we would be able to purchase a full version, as this would be beyond our means and purpose. (Respondent 6)
>
> Many thanks to you for sharing…a nice software and sample data. As a new user and for the people (who are new to) *ArchaeoFusion* studies, it is really educational and useful. (Respondent 8)
>
> I used *ArchaeoFusion* briefly… I processed gradiometer data I collected, …and found the software fairly easy to use. (Respondent 10)

In contrast, most of the respondents who agreed with statement 5 appear to be more experienced users who have used a variety of data types and software. In particular, the benefits of *ArchaeoFusion* for preserving metadata are most pronounced when data from traditional sensors that have long been used in archaeology (resistivity and magnetometry) are combined with newer types of data (EM and GPR), or when the user commonly uses GIS software to combine data. The following comments are from respondents who agreed with this performance objective:

> Before this product (*ArchaeoFusion*), I was using proprietary software, Surfer, IDRISI, and other GIS software to open, transform, analyze data from each type of sensor (GPR, gradiometer (magnetometry), resistance) separately. (Respondent 4)
>
> I have been using *ArchaeoFusion* to process mag (magnetometry) and EM data. I especially like how easy it is to overlay multiple surveys. (Respondent 11)
>
> Traditionally, I have resorted to simple image overlay options in GIS or graphics packages in order to compare and analyze my data. …I have taught a number of undergraduate and graduate archaeological prospection courses in North America and the UK, and when it comes to the data processing and display sections, it is always a challenge to introduce students to a suite of new programs in the time available – and the students always enquire why a single program doesn't exist. It appears that *ArchaeoFusion* could solve all our problems! (Respondent 12)
>
> Excellent to have a single platform for integrating the most commonly used sensors in archaeological geophysics. (Respondent 13)
>
> I found *ArchaeoFusion* very useful as I was able to much more effectively analyze my project data that I had previously been unable to easily compare using more conventional means. (Respondent 14)

Analysis and Conclusions: As with objective 5, it appears that potential *ArchaeoFusion* users differ depending on their degree of experience and expertise. Those with less experience and who use fewer sensors do not see the benefits of *ArchaeoFusion* compared to other software, because they have not used a variety of other software for processing multiple types of geophysical data. Those with more experience see the benefits of *ArchaeoFusion* for saving time when using multiple methods, except for perhaps expert GPR users (as shown with Objective 5), who require more sophisticated GPR processing than *ArchaeoFusion* currently provides.

6.9 Objective 8

Ground truthing enhances the usefulness of geophysical data.

Criteria for success: At least 50% of the inferences made by all evaluation participants that feature anomalies are actual archaeological features will be verified as correct based on the

results of ground truthing. We predict that the two most experienced geophysical practitioners—Mr. Steve De Vlore and Dr. Kent Schneider—will have a higher rate of correct identification of feature anomalies than will members of the User Group that have somewhat less practical experience.

Assessment 1 Results Data: The portion of the geophysical survey chosen for use in the evaluation was not tested during the ground truth phase, so there is no way to evaluate this objective as originally planned. Results from the ground truthing, however, showed an 80% success rate for prediction. In addition, responses to Assessment 2 show strong agreement with the usefulness of ground-truthing.

Assessment 2 Results Data: 86% of Assessment 2 respondents agreed that ground truthing enhances the usefulness of geophysical data.

Assessment 1 Analysis: The ground truthing results conducted at Los Adaes State Historic Site confirmed that 80% of anomalies interpreted to be archaeological features were verified.

Assessment 2 Analysis: 86% of respondents in Assessment 2 agreed with statement 8 that "Ground-truthing (test excavations to evaluate interpretation of geophysical data) enhances the usefulness of geophysical data." The two respondents who marked "neutral" to this statement appear to be novice users, based on their comments, and likely have little or no experience with ground truthing. Respondent 5 stated "I haven't had the ability to fully investigate the software, what I have noticed thus far is that it is user friendly." Respondent 8 (quoted in the previous section) clearly states that she is new to archaeogeophysics.

Conclusions: Despite a lack of data from *ArchaeoFusion* evaluation participants, the ground-truth results from Los Adaes strongly support this objective. Table 5-3 summarizes the results of ground truthing, and shows that 73.3% of the distinct targeted anomalies were confirmed by excavation, and one other was partially confirmed, bringing the success rate to 80%. This is much higher than the 50% success rate criteria for evaluating this performance objective. In addition, 86% of Assessment 2 respondents agree that ground truthing enhances the usefulness of geophysical data.

7.0 COST ASSESSMENT

This chapter describes the costs associated with the implementation of the integrated multi-sensor approach, as well as the cost benefit of the approach.

7.1 COST MODEL

Modeling the costs associated with the adoption of the integrated multi-sensor approach requires the consideration of five cost elements: software purchase: (*ArchaeoFusion*, illustration software); sensor purchase; labor; overhead; training (labor, travel, and tuition); and actual implementation of the integrated multi-sensor approach (labor). Table 7-1 indicates which of the cost factors were quantified using actual data tracked during the 2009 field demonstration, and which were estimated. Details for each cost factor are described in sections that follow.

Table 7-1 Cost Model for Integrated Multi-sensor Geophysical Approach.

Cost Element	Data Tracked During Demonstration	Estimated Costs
Software Purchase *1) ArchaeoFusion* 2) Illustration	1) *ArchaeoFusion* Free For DoD 2) Actual Costs from www	
Sensor Purchase		Standardized At $20,000.
Labor Rate		Existing National Salary Survey Data (Society for American Archaeology)
Overhead Rate		Estimated (Actual Data Scant Due To Confidentiality Issues)
Training 1) Labor 2) Travel 3) Tuition	3) From NPS Course	1) Rate From SAA survey 2) National Average airfare
Implementation Of Approach 1) Demonstration 2) NRHP Evaluation 3) Site Mitigation	1) Labor Rates, Person Days from Demo. 2) Person Days from Demo. 3) Person Days from Demo.	2) Labor Rate Adjusted 3) Labor Rate Adjusted

A decision to adopt the integrated multi-sensor approach also requires a comparison of its costs with those associated with the traditional approach to archaeological site evaluation and mitigation. The traditional approach is based on the hand excavation of shovel tests and small test units. Primary costs of the traditional approach include labor for field investigations, lab analyses, and report preparation. Equipments costs associated with the traditional approach based on hand excavation are negligible (hand tools) or we can assume are already owned by CRM units (GPS and EDM devices). Costs associated with expendable supplies used in fieldwork and lab studies are also negligible. While mechanized removal of the disturbed uppermost soil stratum is used in many state Department of Transportation (DoT) archaeology projects to expose features, it is very rarely used on DoD installations. Additional factors to be considered (but not quantified) in choosing between the integrated multi-sensor and traditional approaches are information return and risk of inappropriate site treatments based on inadequate information return.

7.1.1 NEED FOR COST ELEMENTS

1) ***ArchaeoFusion* purchase cost**

ArchaeoFusion plays a critical role in the integrated multi-sensor approach. It makes the approach possible and serves as the technology infusion tool. The University of Arkansas Center for Advanced Spatial Technologies (CAST) has committed to provide *ArchaeoFusion* in its current form at no cost to all DoD users for 5 years. Alternative plans for generating funds needed for updates of *ArchaeoFusion* are under consideration. There will almost certainly be a purchase cost for *ArchaeoFusion* by non-DoD users. That amount has not yet been finalized.

2) Illustration software

ArchaeoFusion can process data from virtually all of the near-surface geophysical sensor types currently used by archaeo-geophysical practitioners in the US, but it does not (and was never intended to) have sophisticated illustration capabilities. Practitioners generally use labels, lines, and other shapes to identify anomalies and other areas of interest. Some practitioners use extensive outlining (“vectorizing”), often creating separate data layers that can be overlain on other maps or used as a basis for selecting anomalies for ground truthing (Figure 7-1). Microsoft programs used by most DoD employees could be used, although most practitioners would view their capabilities as rudimentary. Geophysical practitioners use a variety of illustration packages, but Golden Software Surfer (currently version 10) is dominant. In addition to graphic capabilities, it has many of the basic features of a GIS (most importantly, the overlay of multiple discrete layers). Some practitioners make use of its “gridding” functions, which include smoothing and contouring, as well as the production of image (continuous gradient) maps that have replaced contour maps for most applications. The current (September 2011) cost for Surfer 10 is $700. Some practitioners use CorelDraw software; the version with the full range of capabilities currently costs $820.

Figure 7-1. Interpretation of an IMS survey at Pueblo Escondido, NM (Kvamme et al. 2006).

3) Training costs

Most geophysical sensors are not highly complex, but all require at least a little formal training, work with an experienced mentor, and most importantly, practical experience. The first surveys done by nearly all users do not provide a reliable basis for decisions about site treatment.

Options for initial training in the use of geophysical sensors include formal university courses (e.g., University of Arkansas, the University of Mississippi, Notre Dame), "on-the-job" training for employees of research units affiliated with universities (e.g., University of Kentucky at Lexington, Indiana University at Bloomington, IPFW Archaeological Survey at Fort Wayne IN), work with CRM firms with in-house geophysical capabilities (e.g., Cultural Resource Analysts, Inc.; Ohio Valley Archaeology), and archaeological field schools sponsored by a wide variety of universities. The National Park Service (NPS) offers several courses in geophysics (which they generally refer to as remote sensing), including the annual, 40 hour, introductory class that played an important role in the demonstration reported here. Tuition for that course is $475, plus travel, lodging, meals, and incidentals. The class is held in various locations around the country. For present purposes, we use the standard federal per diem rate for "the rest of the US" (meaning locations other than large cities and tourist destinations where costs are relatively high): $77 for lodging and $46 for meals and incidentals. The average air fare for all destinations in the US for 2010 was approximately $339.71 (http://www.planetickets.com/airfare.html), and this is used to estimate travel costs. Using these values, the total cost for attending the NPS remote sensing course would be $1748 (rounded up to the nearest dollar).

Proficiency with geophysical sensors cannot be developed in a 40-hour course, particularly when one is learning a first instrument. Individuals with expertise in one instrument can achieve proficiency in others much faster, once they have a knowledge base to build on. Geophysical instruments vary in terms of the amount of practical experience required to consistently collect

good quality data (Table 7-2). GPR is undoubtedly the most difficult, followed by magnetometry. The theory underlying electromagnetic induction is quite complex, but using the instrument and getting good quality data are quite easy, particularly using *ArchaeoFusion*. For those using other software, processing conductivity data collected using certain models of the Geonics EM38 is difficult, due in part to a delay in data logging (Clay 2006). The most straightforward method to master both in the field and understanding of the theory is electrical resistance (Ernenwein and Hargrave 2007).

In terms of data processing, GPR is again the most difficult, followed by conductivity, magnetic susceptibility, magnetics, and resistance. We assume that typical users can achieve minimally adequate proficiency in data collection and processing with relatively simple methods such as electrical resistance and electromagnetic induction in four weeks (160 hours). This would include attending the NPS or comparable class, working closely with a competent mentor on at least several small surveys, and then working independently on several surveys. In addition to fieldwork, the trainee would process data, first with direct input from a mentor, and then independently with a mentor's feedback on the results. The ideal situation is for the mentor to be present in the field, at least during the second week. In reality, this may not be possible, but *ArchaeoFusion* makes it easy to email data processing sequences and the associated images of results.

If circumstances demand the novice to learn GPR first, more than four weeks may be necessary, depending on the trainee's aptitude, motivation, and the nature of sites selected for his or her training surveys. If GPR (or, to a lesser extent, magnetics) is learned as a 2nd , 3rd, or 4th technique, 4 weeks is likely to be adequate. Table 7-2 compares the instruments in terms of the ease of processing data, the overall learning curve, and other relevant factors.

Table 7-2. Relative difficulty learning and using sensors (Ernenwein and Hargrave 2007).

	Survey Speed	**Ease of Processing**	**Learning Curve**	**Data Density**	**Other Positives**	**Other Negatives**
Magnetics	rapid	easy	moderate	moderate	dual sensor options	Metal clutter
Resistance	slow	easy	easy	low	least demand for vegetation clearing	Physically demanding
GPR	moderate	complex	steep	high	depth information	
EMI	rapid	slow	moderate	moderate	2 different data sets; No probe insertion	drift problems

7.1.2 Labor Rates

1) Salary

Labor costs have two components, salary and overhead (including fringe benefits). The best data on salaries is the "2005 Salary Survey" of professional archaeologists in the US. The survey was conducted by Association Research, Inc. for the Society for American Archaeology and Society for Historical Archaeology, the two largest professional archaeological societies in the US. That

study reported salary data for many subgroups based on job title (function), experience, gender, highest degree, organization type (federal, CRM firm, etc.), and region. One group that the salary survey did not include was non-supervisory fieldworkers. They are made up of students and a small cadre of itinerate field workers, many of whom move from one temporary job to another, often receiving no benefits other than room and board. The individuals who comprise the CRM staff on military installations unfortunately were not broken out as a discrete category for the survey. Some of these archaeologists are federal (commonly GS11) employees, whereas others are employees of large CRM or multi-disciplinary firms working one or multi-year contracts with full benefits.

The mean salary for all survey respondents (n=2,143) was $50,558, and the median was $50,000. The mean for federal archaeologists is significantly higher ($63,201). Federal archaeologists are relatively well-paid, but the mean is probably affected by many people in supervisory grades (GS12 and higher) in various agencies who don't spend much of their time doing fieldwork. The average for all archaeologists working in a CRM (typically, consulting firms) setting was $40,946—substantially less than federal archaeologists.

The Bureau of Labor Statistics (http://www.bls.gov/oes/current/oes193091.htm) treats archaeologists and anthropologists as a single category, and reported the mean (for May 2010) hourly wage as $27.07 and the mean annual wage as $58,040. *Simply Hired.com*, a job search web site, reports an overall mean salary for archaeologists of $43,000 (http://www.simplyhired.com/a/salary/search/q-Archaeology). For the present cost analysis, we will use the overall median of $50,000 reported by the SAA Salary Survey. That value falls roughly between the CRM and federal category means, and near the midpoint of the range based on the BLS and *Simply Hired.com* values.

2) Overhead

A second major component to labor costs is overhead (OH). This is an amount—in addition to salary—that is charged to a customer to offset an organization's expenditures in facilities, vehicles, support personnel, marketing, etc. An employee's fringe benefits are generally calculated separately, but in the interests of simplicity, we assume here that they are included in OH. Very little comparative information is available on OH rates in CRM (a web search yielded little useful information). Consulting firms are reluctant to reveal those rates (which play a critical role in their ability to win competitive bids) in contexts other than contractual agreements. Information gleaned from sources such as capability packages submitted by firms competing for Indefinite Delivery Indefinite Quantity (IDIQ) contracts awarded by ERDC are confidential and cannot be revealed. In the author's experience, universities often charge 20 to 50% OH. Overhead rates in the lower end of that range are sometimes charged for CRM work that is conducted primarily off-campus, whereas the higher rates are charged for projects that make extensive use of the organization's infrastructure. Universities that participate in the Cooperative Ecosystems Studies Unit are required to charge 17.5% (http://ucanr.org/sites/CCESU/files/70740.pdf). That low OH rate is one of the factors that make CESU agreements very attractive to the federal government. CESU agreements are not, however, intended to be used for standard archaeological survey and NRHP evaluation projects. A-76 studies conducted as part of the federal government's requirement to obtain goods and services

from the private sector when that makes economic sense, (http://www.census.gov/procur/www/a-76-studies.html) assume an OH rate of only 12% for the government. Some private sector interests have contended that that is unrealistically low. The same source (http://www.fas.org/sgp/crs/natsec/RL30392.pdf) notes that an OH rate of 40% is viewed as "the standard" in the Information Technology sector. It is unclear how comparable that industry is with CRM. Individuals working in the two industries have very different training, skill sets, and relationships with technology. The New York State Department of Transportation has published a table (https://www.nysdot.gov/portal/page/portal/main/business-center/consultants/consultants-repository/ohrates112007.pdf) showing "Current Industry Overhead Rates as of November 16, 2007" that are "appropriate for estimating the approximate "cost use" of engineering/architectural… " (A&E) "…services". Those rates are more likely to be directly relevant here, since some A&E firms have in-house CRM capabilities. The 65th percentile for "moderately complex" A&E projects in upstate NY are 161% for office work and 126% for field work, with a combined rate of 151%. In their article "Cultural Resource Management and American Archaeology" Green and Doershuk note in passing (and with apparent disapproval) that "Overhead (sometimes 150-200% of archaeologists 'wages) often is used to support nonarchaeological endeavors and corporate infrastructure (Green and Doershuk 1998:137)."

In contrast, very small (1 or 2 person) CRM firms that operate out of home offices or other modest quarters are able to maintain very low OH rates, often focusing on very small and/or specialized projects that large firms could not do in a cost-effective manner. Here it is appropriate to avoid extremes at both ends. We suggest that an OH rate of 100% is realistic for medium to large CRM firms, including the large multidisciplinary companies that provide technical personnel to many installations. An OH rate of 100% means that an employee making $50,000 per year would cost the employer $100,000. Assuming 2,080 labor hours per year yields an hourly rate of $48.08 (rounded here to $48). This is the value that we use to estimate the costs of both training labor and day-to-day work.

7.1.3 SENSOR PURCHASE COSTS

The cost associated with the acquisition of geophysical instruments is the most significant cost element in the short term. Table 7-3, which lists the sensors whose data can be downloaded and processed by *ArchaeoFusion*, provides a good idea of the diversity of instruments available to and suitable for archaeologists. Costs are variable but priced competitively within each general category. That is, GSSI and Sensors & Software both manufacture GPR systems and provide specialized software, and compete for the same customer base. Far more GPR systems are purchased for environmental (e.g., detection of buried tanks or drums) and infrastructure applications (e.g., evaluating the integrity of concrete structures, detection of subsurface utilities) than for archaeology, and prices are set by and for that market. Interestingly, in those work areas, sensors represent investments that can generate very substantial returns. For example, customers expect to pay rates that are very high (by CRM standards) for the detection of toxic wastes that could represent health hazards and enormous financial liabilities. In archaeology, sensors represent investments that primarily reduce labor costs and enhance information return. Given this, it is interesting that sensors designed primarily for archaeological applications (e.g.,

Bartington and Geoscan Research gradiometers and the Geoscan Research RM15 resistance system) are comparably priced to GPR systems with a very broad range of applications.

Table 7-3. List of sensors whose data can be loaded into and processed by *ArchaeoFusion*.

Magnetometry	Electromagnetic Induction	Resistivity	Ground-penetrating Radar
Bartington Grad601-2	Geonics EM38MK2	Geoscan RM15	GSSI SIR-3000
Bartington Grad601	Geonics EM38B	Geoscan RM4	GSSI SIR-10
Geoscan FM18	Geonics EM38DD	TRCIA	GSSI SIR-20
Geoscan FM36	GSSI EM Profiler		GSSI SIR-2000
Geoscan FM256			S&S Noggin
Geometrics G-858			S&S PulsEKKO Pro

Nearly all of the systems listed in Table 7-3: are priced in $15,000 to $25,000 range. For example, two gradiometer systems (produced by different manufacturers) and a GPR system purchased by ERDC in 2006-2007 (and which all represented the most recent models at that time) ranged between $18,593 and $22,420. For present purposes, we estimate the cost of all instruments at $20,000. There are several important reasons for not considering relatively minor differences in sensor costs. Most importantly, decisions about which instruments to purchase should be based on the nature of the archaeological deposits, soil, moisture, and vegetation characteristics of sites in the region where they will be used. Choosing between electrical resistance and GPR based primarily on cost rather than site conditions would be foolish. A savings of several thousand dollars would be meaningless if the instrument purchased was not well suited to local conditions. Similarly, a difference of several thousand dollars in the cost of gradiometers would be offset in a few weeks or months by labor costs if there is a difference in efficiency (e.g., ease of setup, memory limitations determining the proportion of time needed for data transfer, ergonomic factors, and the potential for use in wooded as well as open areas). Secondary reasons to avoid quoting actual costs include fluctuation in cost as a correlate of exchange rates, and the need for a federally sponsored study to avoid apparent favoritism.

Even a single instrument, if properly chosen and used, can significantly enhance a CRM program's capabilities. To develop a really effective and versatile in-house geophysical capability, however, one should acquire at least two instruments. Use of multiple instruments will increase the likelihood of detecting at least some features at a wider range of sites, permit the detection of a broader range of feature types at individual sites, and will thus make both positive and negative findings more reliable. Generally the primary instrument should be the one that is the most effective at the widest range of sites, while the secondary instrument can provide complementary information. Realistically, of course, the primary and secondary roles will be reversed for some sites, and sometimes only one technique or neither will be successful.

Additional instruments should be added to the inventory once the primary and secondary methods have been established and the cost and information return benefits of geophysics have been demonstrated to financial decision makers. Recommended procedures for choosing instruments are provided in Ernenwein and Hargrave (2007:153-155).

Table 7-4 shows that the cost of purchasing two sensors and training a user is approximately $58,500. While this amount is not insignificant, it represents an investment in a capability that will reduce the costs and increase the information return of future archaeological investigations at many sites over the course of many years. The only real difference in the cost of a second, third, or fourth instrument is a modest decrease in labor costs associated with training.

Table 7-4. Cost of purchasing sensors, software, and training.

	Purchase	**Training**	***ArchaeoFusion***	**Graphics software**	**Total**
Sensor 1	20,000	9,428[1]	0[3]	700	30,128
Sensor 2	20,000	7,668[2]	0[3]	700	28,368
Sensor 3	20,000	5,748	0[3]	700	26,448
Sensor 4	20,000	5,748	0[3]	700	26,448

1 NPS course, TDY, 160 hrs labor

2 160 hrs labor

3 No cost for DoD users

The use a second, third or fourth instrument in a particular project has significant impacts on use costs. Collecting data with a second instrument (over the same area as the first) will *roughly* double the cost of data collection. Using a third instrument on the same area will *roughly* triple the cost (we say roughly because the instruments differ in data acquisition rates).

7.2 COST DRIVERS

Cost drivers are conditions or practices that may alter the range of variation in one or more of the cost factors. The important cost factors for this project (Table 7-1) include costs for purchasing software (*ArchaeoFusion* and supplemental graphics software) and sensors; and expenditures (labor, tuition, and travel) for training and actual sensor use. Software costs are negligible. We have estimated the cost for sensors at $20,000 each. Using a standard sensor cost reflects the importance of making decisions about which sensors to acquire based their suitability for conditions present on particular installations rather than on minor differences in purchase cost. Labor costs associated with actual sensor use are important because they quickly become far greater than sensor and software purchase costs. No cost drivers are apparent that would cause labor rates to vary greatly over the foreseeable future.

Our cost model assumes that sensors are appropriate to local conditions, used effectively, and yield the kind of information needed to evaluate or mitigate sites. Some level of inefficiency in sensor performance would be acceptable, given the substantial cost and performance advantages (discussed below) that the integrated multi-sensor approach has over the traditional approach. Ineffective sensor use can be corrected by training and experience. We assume that most installations have enough variation in site condition that no sensor will be suitable for all sites. By definition, the multi-sensor approach assumes use of at least two sensors, and hopefully at least one of them would prove to be effective. Protracted use of a sensor that is not suitable for the sites being investigated could threaten the favorable balance of costs and benefits that should accompany adoption of the integrated method.

The importance of selecting sensors that are well-suited to the site characteristics and other conditions that exist at a particular installation was recognized at the inception of this project. A separate guidance document, *Archaeological Geophysics for DoD Field Use: A Guide for New and Novice Users* (Ernenwein and Hargrave 2007), was developed to meet this need. Topics addressed in detail include fundamental geophysical concepts; how the various methods work; how to assess a site or installation's suitability for use of the integrated multi-sensor approach; select geophysical method and sensors; design a field strategy; estimate time and cost; and integrate geophysics into a CRM program. In essence, Ernenwein and Hargrave (2007) provide the technical information needed to implement the integrated multi-sensor approach while the present document provides the information needed to assess the costs and benefits. While it is not productive to reiterate here a great deal of the guidance document's content, it is useful to identify characteristics of archaeological sites or (in a more general sense) entire installations that will influence sensor performance.

Table 7-5 (adapted here from Ernenwein and Hargrave 2007) shows the general effect of site conditions on each of the sensor types. For example, a common problem for magnetic surveys at military installations is the presence of magnetic clutter associated with recent metallic trash. Table 7-5 shows that the clutter is problematic for magnetometry, may be a cause of concern for conductivity, but is not relevant for GPR or resistance. Most installations have metallic debris on at least some sites, and that alone is not a sufficient reason to exclude magnetometry from consideration. Clutter associated with magnetic rock is less common but may have a stronger negative impact on the usefulness of magnetometry. That was found to be true at Fort Bragg (NC), where magnetic sandstone is very common but archaeological features are very rare. In contrast, magnetic rock was present at Presidio Los Adaes but did not negate magnetometry's usefulness (in part because of the presence of numerous, high contrast features).

Table 7-5 Site Conditions that Influence Sensor Performance.

Condition	Resistance	Conductivity	GPR	Magnetic Susceptibility	Magnetometry
Extremely Dry	P	P	C	N	N
Dry	C	N	B	N	N
Moderately Moist	B	B	B	N	N
Moist	B	N	C	N	N
Saturated	P	C	C	N	N
High % Clay Minerals	N	N	P	N	N
Moderate To High Salinity	N	N	P	N	N
Abundant Non-Magnetic Rock	C	N	C	N	N
Abundant Magnetic Rock	C	N	C	N	P
Magnetic Bedrock Near Surface	N	N	N	N	P
Metal Ferrous Debris On Surface	N	C	N	N	P
Large Metal Objects	N	N	N	N	C
Poorly Developed Soil	N	N	N	C	C
Well Developed Soil	N	N	N	B	B

B= Beneficial, C= Causes Concern, N= No Effect, P= Problematic.

A second important issue that is discussed at some length in Ernenwein and Hargrave (2007) is vegetation. All of the methods require a sensor to be moved systematically across the surface along closely spaced transects. Deviations from the traverse to avoid obstacles degrade horizontal spatial control, making it more difficult to detect and reliably map anomalies (particularly small anomalies). Resistance is perhaps the most versatile technique in this regard, since one can take the time needed to maneuver the instrument around obstacles to the proper location. Resistance is, however, the slowest technique under ideal circumstances, and its use in areas with many obstacles will exacerbate that problem. Fortunately, many problems with

vegetation can be overcome by collecting data during the favorable season or clearing vegetation.

A third issue that is highly relevant to sensor selection is the nature of the archaeological deposits that occur at an installation. As explained, geophysical survey is best suited for detecting discrete features rather than broad deposits. Installations (for example, Fort Bragg) whose sites are characterized by relatively few features will see much less benefit from the integrated multi-sensor approach that will installations whose sites have many features.

Given the importance of selecting the most suitable sensors, those planning to purchase instruments should consult with local geophysical practitioners and experiencedDoD users. Such consultation is well worth the cost of bringing reliable consultants to the installation to acquire a first-hand familiarity with local conditions. Ideally, an installation should arrange for an experienced practitioner to conduct several small surveys at representative sites to better assess which sensors are most suitable. This approach should allow future users to avoid purchasing sensors that are not well suited to their needs, and thus largely remove sensor performance as a major risk to the successful adoption of the multi-sensor approach.

7.3 COST ANALYSIS AND COMPARISON

7.3.1 Comparison of Integrated Multi-sensor and Traditional Approaches

We will compare the costs and benefits of the integrated multi-sensor and traditional approaches in the context of two scenarios. The first scenario views the geophysical and ground truthing work actually done at Los Adaes as an example of the kind of NRHP eligibility evaluation of a complex site that could be conducted at many military installations and civilian settings. We will first look at scenario 1 using the actual cost data from the Los Adaes field demonstration. We will then revise several of the actual labor costs (which happened to be unusually low) using estimates based on the rate of $48/hour.

The second scenario will consider how our actual work at Los Adaes could be expanded into an archaeological mitigation project, and compare a site mitigation using the integrated multi-sensor approach with one based on the traditional approach. The parameters of the traditional mitigation will be based on the archaeological investigations conducted at Los Adaes prior to this project (Gregory et al. 2004).

Geophysical and Ground Truthing Costs:

Table 7-6 shows the area of survey for each geophysical method used at Los Adaes, along with the number of hours expended. This work was accomplished by three individuals (Lockhart, Hargrave, and McKinnon) over the course of approximately 5 work days. The average coverage rate for all of the instruments used was 22 person hours per ha. At a rate of $48 per hour, collecting the unprocessed data for the survey areas reported in Table 7-4 would cost approximately $5,812.

Table 7-6. Person hours required for geophysical survey at Los Adaes.

Method	Area of survey	Person hours
Electrical resistance	.87 ha	30.9 hrs
Magnetic gradient	1.3 ha	21.97 hrs
Magnetic susceptibility	.7 ha	10.5 hrs
Conductivity	.7 ha	10.5 hrs
GPR	.6 ha	9 hrs
Grid setup	1.3 ha	29.25 hrs
Additional rope moving	n.a.	8.97 hrs
Combined survey area	5.47 ha	121.09 hrs

Table 7-7 shows the additional costs directly associated with the geophysical survey. These include labor associated with travel, data processing, and data interpretation, as well as standard federal TDY costs (lodging, travel, and meals). We do not include costs associated with writing a separate report for the geophysical investigations, as that would be a component of the ground truthing report. Inclusion of these cost factors brings the total cost for the geophysical survey actually done at Los Adaes to $16,955.

Table 7-7 also shows the costs associated with the ground truthing investigations actually done at Los Adaes. The ground truthing work was limited by our project budget and sole source contracting rules to a maximum of $25,000. Based on previous investigations of a similar nature (Kvamme et al. 2006), we believed that the necessary work could be done for that amount. We wanted to award the ground truthing to Dr. George Avery and/or Dr. Pete Gregory because of their unique knowledge of the site based on previous excavations (Gregory chose to work with Avery as an unpaid but very important consultant). We did not anticipate that Avery's salary would be subsidized by Stephen F. Austin State University, or that students working for slightly more than $8/hr would be available to conduct much of the artifact processing. Additionally, the field crew paid for their lodging and meals and thus, worked at a relatively low rate. Those highly competent field archaeologists were willing to do so for the opportunity to work at a Spanish presidio, a type of site that they both found particularly interesting. Together, these favorable rates made it possible for the ground truthing effort to include the excavation of 15m^2 for a total cost of $24,946. Combined actual costs for the geophysical and ground truthing investigations at Los Adaes were $41,904.

Table 7-7. Summary of geophysical survey and ground truthing costs using actual rates (where available).

Work type	Cost components	Days, miles	Rates ($.38/mile; $48/hr)	Cost
Geophys.	Survey labor	3 persons, 5 days	$48/hr	$5,760
Geophys.	Travel (round trip + local miles)	880 miles	$.38/mile POV	$335
Geophys.	Travel labor	3 persons, 2 days	$48/hr	$2,304
Geophys.	Lodging	18 nights	$77/night	$1,386
Geophys.	Meals	21 days	$46/day	$966
Geophys.	Data processing	40	$48/hr	$1,920
Geophys.	Data Interpretation	24	$48/hr	$1,152
Geophys.	Report preparation	60	$48/hr	$2,880
Geophys.	Pro-rated cost sensor purchase	n.r.	n.r.	n.r.
Geophys.	Pro-rated cost sensor use	n.r.	n.r.	n.r.
Geophys.	Pro-rated cost training	n.r.	n.r.	n.r.
Geophys.	Total			$16,955
Ground Truth.	Project director	0	0	0
Ground Truth.	Excavation labor[1]	2 persons, 12 days	$31.25/hr	$6,000
Ground Truth.	Travel	Rental van		$1,530
Ground Truth.	Lodging	1 person, 12 days	$60/night	$720
Ground Truth.	Meals	0	0	0
Ground Truth.	Lab analyses labor	Student workers	$8.16/hr	$4,896
Ground Truth.	Lab analyses labor (metal)	24 hrs	$43.75/hr	$1,400
Ground Truth.	Faunal	Hours unspecified	Rate unspecified	$500
Ground Truth.	Report preparation labor	Hours unspecified	Rate unspecified	$2,700
Ground Truth.	Supplies			$1,700
Ground Truth.	Overhead		28.3%	$5,503
Ground Truth.	Total			$24,946
Both	*Total*			*$41,904*

[1] Ground truthing project director salary not charged to project.
[2] No meals provided.
n.r. = not relevant. Annual operating budgets for CRM programs on military installations do not pro-rate purchase and use costs of major items or training across multiple years. If authorized, items are purchased via one-year budget plus-ups or using OH funds from their parent organization. Here we assume the individual trained in sensor use continues work through subsequent years, hence training costs do not appear in typical year represented here.

Table 7-8 shows a revised cost structure for the ground truthing conducted at Los Adaes. Here we estimate the costs for Avery and the field crew's salary at $48/hr. The two field crew members each worked 96 hours. A rule of thumb used by many CRM archaeologists is that the lab analysis and report write-up requires twice the number of hours spent in the field. That ratio is appropriate for projects (like the Los Adaes investigations) that recover a substantial amount of artifacts and encounter numerous features (projects that involve less excavation and encounter few features or artifacts sometimes have ratios as low as 1:1). Assuming that Avery worked 288 hours at $48/hr increases his cost to $13,824. Using a rate of $48/hr and adding travel, lodging, and meals at the federal rate brings the field crew cost to $14,076. We have also increased the labor costs for the metal analysis to $48/hr. We have decided not to alter the cost of the student workers. These were very inexperienced individuals, and one might assume that experienced

analysts making $16/hr might accomplish the same work in half the time. A labor rate of $16/hr is roughly comparable to that often paid to itinerate field workers hired on a temporary basis. These increases bring the ground truthing component to $44,404 and the total effort (geophysical and ground truthing) to $61,359. These (revised) amounts are used in the following comparisons.

Table 7-8. Geophysical and ground truthing costs using a standard rate of $48/hr for all labor other than student workers (bold print indicates categories that were revised).

Work type	Cost components	Days, miles	Rates ($.38/mile; $48/hr)	Cost
Geophys.	Survey labor	3 persons, 5 days	$48/hr	$5,760
Geophys.	Travel (round trip + local miles)	880 miles	$.38/mile POV	$335
Geophys.	Travel labor	3 persons, 2 days	$48/hr	$2,304
Geophys.	Lodging	15 nights	$77/night	$1,386
Geophys.	Meals	21 days	$46/day	$966
Geophys.	Data processing	40	$48/hr	$1,920
Geophys.	Data Interpretation	24	$48/hr	$1,152
Geophys.	Report preparation	60	$48/hr	$2,880
Geophys.	Pro-rated cost sensor purchase	n.r.	n.r.	n.r.
Geophys.	Pro-rated cost sensor use	n.r.	n.r.	n.r.
Geophys.	Pro-rated cost training	n.r.	n.r.	n.r.
Geophys.	Total			$16,955
Ground Truth.	*Project director*	*288 hrs*	*$48/hr*	*13,824*
Ground Truth.	*Excavation labor*[1]	*2 persons, 12 days*	*$48/hr*	*$9,216*
Ground Truth.	Travel	Rental van		$1,530
Ground Truth.	*Lodging*	*3 persons, 12 days*	*$77/night*	*$2,772*
Ground Truth.	*Meals*	*3 persons, 12 days*	*$46/day*	*$1,656*
Ground Truth.	Lab analyses labor	Student workers	$8.16/hr	$4,896
Ground Truth.	*Lab analyses labor (metal)*	*24 hrs*	*$48/hr*	*$1,152*
Ground Truth.	Faunal	Hours unspecified	Rate unspecified	$500
Ground Truth.	Report preparation labor	Hours unspecified	Rate unspecified	$2,700
Ground Truth.	Supplies			$1,700
Ground Truth.	Overhead[1]		28.3%	$4,458
Ground Truth.	Total			$44,404
Both	Total			$61,359

[1] OH not charged on labor rates of $48/hr (that amount includes 100% OH)

n.r. = not relevant. Annual operating budgets for CRM programs on military installations do not pro-rate purchase and use costs of major items or training across multiple years. If authorized, items are purchased via one-year budget plus-ups or using OH funds from their parent organization. Here we assume the individual trained in sensor use continues work through subsequent years, hence training costs do not appear in typical year represented here.

7.3.2 EVALUATING NATIONAL REGISTER ELIGIBILITY STATUS

Determining if an archaeological site is eligible for nomination to the National Register of Historic Places (NRHP) will be the most common application of the integrated multi-sensor approach. Mitigating the intentional destruction of a site that represents an obstacle to training or infrastructure development is a second type of application. Site mitigations are frequently done by state Departments of Transportation, other agencies, and certain commercial development projects, but are currently rarely conducted by the Army, largely because of cost. Adoption of the integrated multi-sensor approach will make them economically more feasible.

An NRHP eligibility evaluation requires several kinds of information that provide a basis for assessing the usefulness and adequacy of information return from an integrated multi-sensor study. To be eligible, a site must 1) have integrity of location, design, setting, materials, workmanship, feeling, and association. "A property with good archaeological integrity has archaeological deposits that are relatively intact and complete". This is often manifest by "Spatial patterning of surface artifacts or features that represent differential uses or activities; Spatial patterning of subsurface artifacts or features; or Lack of serious disturbance to the property's archaeological deposits" (Little et al. 2000:37). An eligible site must also 2) be significant in terms of at least one of the four established criteria listed in Table 7-9. Significance must be evaluated relative to one or more historic contexts, which are written statements that summarize information about historic properties that share a common place, theme, and time, and that can be used to assess a particular property's significance (Nelson n.d., http://www.parks.ca.gov/pages/1072/files/writing%20historic%20contexts.pdf). Relating a site to a relevant historic context requires chronological information and determination of the property's location and boundaries.

Table 7-9. National Register of Historic Places criteria **(http://www.achp.gov/nrcriteria.html).**

(a) Association with events that have made a significant contribution to the broad patterns of our history. (b) Association with the lives of persons significant in our past. (c) Embodiment of distinctive characteristics of a type, period, or method of construction, or that represent the work of a master, or that possess high artistic values, or that represent a significant and distinguishable entity whose components may lack individual distinction. (d) Information important in prehistory or history.

Scenario 1: An integrated multi-sensor approach to evaluating the NRPH eligibility of Presidio Los Adaes.

Los Adaes had been determined to be eligible for the National Register of Historic Places before the inception of this project. The site is so important that it had also been designated as a National Historic Landmark. Los Adaes had been a strong candidate for these designations based on the existence of historic maps and a rich body of archival information. Gregory's early excavations verified the site's identity and documented the presence of intact archaeological deposits (Gregory et al. 2004). His subsequent excavations (Figure 7-2) addressed various

research topics, but much of the excavation was conducted to explore the extent to which the actual site conformed to the historic maps.

We contend that our geophysical survey and ground truthing would have provided more than enough information to determine that the side is eligible for the National Register. The geophysical data provided information about the spatial extent of the presidio (the only portion of the site considered in this study). The fort's distinctive layout was discernible in the geophysical data, indicating that the site is, in fact, the same one depicted by the 1720 and 1767 maps. The geophysical imagery also demonstrated integrity in one of the ways listed above: Intact spatial patterning of subsurface features (and by extension, the artifacts they contain). Most of the 15 ground truthing excavation units confirmed the existence of intact deposits, further documenting good integrity. In fact, a decision about the site's NRHP eligibility could have been based on much less work than we conducted. All of the geophysical data sets (except, perhaps, the GPR data) conveyed enough information to tie the site to the historic maps and demonstrate intact patterning of subsurface features. Similarly, all the surveys included anomalies that indicated the exact location of at least some features. Minimally, geophysical survey using one sensor and a few excavation units could have provided the information needed to evaluate the site. The magnetic susceptibility, conductivity, or magnetic gradient would have provided fully adequate data; and the resistance data would have been adequate. Only the GPR was disappointing at Los Adaes. Survey using one sensor could almost certainly have been accomplished for 25% of the corrected total cost of $61,359, that is, for approximately $15,339.

Table 7-10 compares the estimated costs for evaluating the NRHP status of Los Adaes using three approaches: 1) the integrated approach using only two sensors and ground truthing of 7.5 m^2; 2) the integrated multi-sensor approach as demonstrated by this project (i.e., use of five sensors and ground truthing of 15 m^2); and 3) the traditional approach with no geophysics and excavation of 30 m^2.

Table 7-10 Comparison of costs associated with the integrated multi-sensor and traditional approaches for evaluating the NRHP status of Los Adaes.

Approach:	**Integrated Multi-sensor**		**Traditional**
Version:	1	2	n.r.
Geophysics Cost ($)	8,478	16,955	n.r.
Sensors (n)	2	5	n.r.
Excavation Cost ($)	22,202	44,404	88,798
Area (m^2)	7.5	15	30
Total Cost ($)	30,680	61,359	88,798

Note: Version 2 was demonstrated. The scaled-down version 1 could have been adequate for a basic NRHP evaluation.

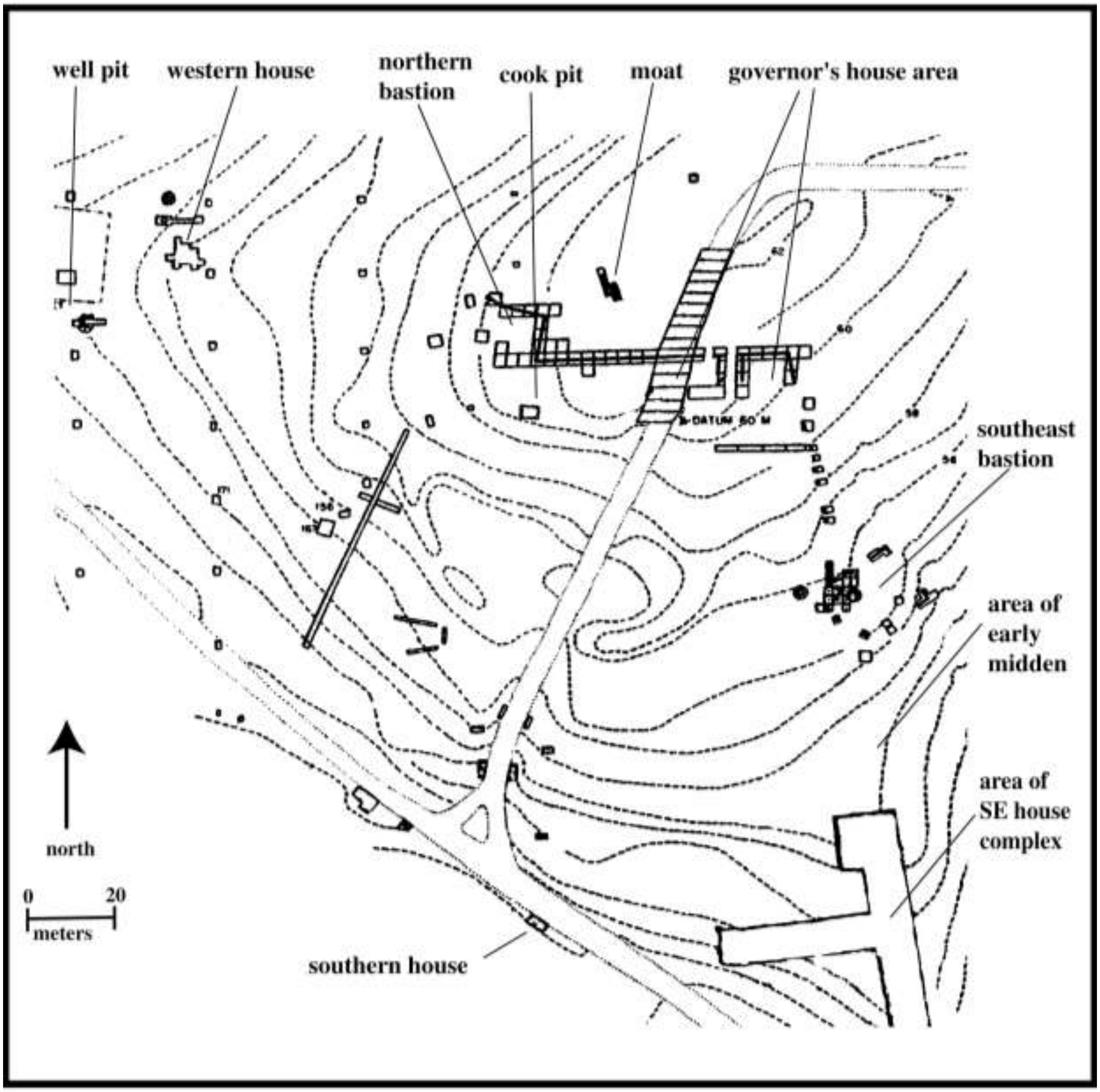


Figure 7-2. Map showing previous excavations at Los Adaes (Avery et al. 2011; Gregory et al. 2004).

How much would it cost to determine the site's NRHP eligibility using exclusively a traditional approach? The historic maps of Los Adaes represent a huge asset that is not available for most historic sites and all but a few prehistoric sites. Even with the maps, Gregory conducted rather extensive excavations to verify the existence, location, and nature of the site's main features (the palisade, moat, and internal structures). Much of that work was necessary even after one of the palisades had been located, providing a basis for using the maps to predict the location of the other walls and internal structures.

Given their size, it might not have been too difficult to locate units within the structures (Gregory did not attempt to locate any of the internal structures other than the Governor's house). Based on our experience in the ground truthing effort, units located in many portions of the structure interiors may have been difficult to interpret. Intersecting the large burned clay features that Avery documented in Units 4 and 8 would have required very good luck. Nearly all of the ground truthing units were targeted on discrete anomalies thought to be features, but several of those encountered piles of midden or other sediments (Units 2, 3, and 17) rather than the predicted facilities such as storage pits. Several other units revealed amorphous or no features (e.g., Unit 1). Such ambiguous results would have been much harder to interpret in the absence of geophysical images showing the site's *actual* coherent spatial patterning (Gregory had to do substantial work to demonstrate that the historic maps are, in fact, quite reliable). While there is no basis for a firm estimate, it is reasonable to suggest that at least 30 units (rather than the 15 we excavated) would need to have been necessary to have a reasonable chance to identify at least several major features needed to confidently demonstrate that the site had integrity. Doubling the amount of excavation, artifact analysis, and other cost factors would have increased the cost of excavations from $44,404 to $88,808 (Table 7-10).

Once costs associated with sensor acquisition and training have been absorbed, geophysical survey can provide far more complete information about site layout or the distribution of anomalies than excavations that are substantially more expensive. Some ground truthing excavation is virtually always essential to assess the integrity of site stratigraphy, or distributions of features and/or artifacts. The many sites that exhibit little or no obvious patterning (e.g., Woodland period sites characterized by a seemingly random scatter or anomalies—only some of which are likely to be pits or hearths) would require more extensive ground truthing. Several strategies have been demonstrated elsewhere (Hargrave 2006; Kvamme et al. 2006), including a) the excavation of anomalies judged most likely to be features (in order to minimize excavation costs), and b) assigning anomalies to descriptive or functional categories and then excavating a representative sample, in hopes of generating an idea about the diversity of feature types.

Scenario 2: Mitigation (Data Recovery)

When it is determined that adverse effects to a historic property cannot be avoided, the Section 106 process requires consultation to identify an appropriate mitigation plan. For archaeological sites, mitigation sometimes entails the recovery of scientific data that would otherwise be lost by site destruction. Large scale data recovery of complex sites can be very expensive, largely because of the labor costs associated with excavation, analysis, and dissemination of the results. The integrated multi-sensor approach provides an option for reducing the amount of excavation required to recover adequate information from a representative sample of the site's deposits.

Investigations of Los Adaes conducted prior to the effort reported here (Figure 7-2) convey the potential level of effort and costs (Gregory et al. 2004). Sixty-three 1x1 m units were hand excavated at 12 m intervals along two transects spaced 20 m apart in an unsuccessful effort to locate the western palisade. In summarizing that effort, Gregory indicated that the palisade could have been destroyed by clear-cutting prior to the State's acquisition of the land, "…however, it seems more likely that the excavation strategy was too limited to find this section" (Gregory et al. 2004:70). Gregory conducted those excavations using unpaid Field School students, and his own salary and certain other expenses were subsidized by NSU. In an actual CRM setting,

however, using the cost structure described here, that work alone would have cost $186,496. Most of those units probably produced few artifacts, of course, but even if one removed all costs associated with artifact analysis, the cost would still be $151,213. That amount would purchase 4 sensors, pay for training in their use, pay for the geophysical survey actually conducted at Los Adaes ($128,395), and still leave $22,817 for some carefully targeted ground truthing. While these cost estimates may sound high, they pertain only to the hand excavation of 63 m^2 along the western periphery of the site. Examination of Figure 7-2 indicates that this represents only a fraction of the previous excavations conducted at the site. Mitigating the destruction of a site the size and complexity of Los Adaes would cost at least several times that amount, assuming that the SHPO and other stakeholders participating in the consultation would be willing to accept the excavation of only a portion of the site.

7.3.3 LIFE CYCLE COSTS

No detailed analysis of life cycle costs is warranted. Other than direct and indirect costs associated with labor, transportation within the installation, and expendable supplies of negligible cost (ropes, stakes), the only costs associated with adoption of the integrated multi-sensor approach are procurement of the sensors and software. *ArchaeoFusion* is free toDoD users. The recommended supplemental graphics software costs from $700 to $820. Thus, the only life cycle cost other than sensor purchase is sensor maintenance (repair, upgrade) and replacement.

No written information on sensor use life has been found, but first-hand experience attests to their durability and longevity. The authors are still using GPR, EMI, resistance, and magnetic gradient instruments purchased more than 10 years ago, and are familiar with no cases where instruments owned or used by colleagues have become inoperable simply through normal use. Sensor manufacturers offer periodic upgrades, with the most substantive benefits being increased memory capacity. In the past 10 years, the changes in sensor technology that have most reduced sensor use costs have been the appearance of dual gradiometer systems that nearly double the rate of coverage or data density, and cart-mounted GPR systems that allow all aspects of data collection to be accomplished by one individual. Those advances are now standard features that are reflected in the estimated sensor costs presented here. An important advance over the next few years will be the availability of cart-mounted resistance systems. These promise to make electrical resistance coverage rates and (to a lesser extent) data density capabilities comparable to those of the other major sensor types. No commercial system is yet on the market, however, so they are not considered here.

Note that no costs for sensor purchase and use and training costs are shown in Tables 7.7 and 7.8. CRM programs (typically representing a Branch in a Division organization) do not pro-rate the purchase or use costs of major items across multiple years. If authorized, items are purchased via a one-year budget plus-up or using OH funds from the parent organization (e.g., the Division). Here we assume that the individuals trained in sensor use continue to use the sensors across subsequent years. Thus, training costs are not incurred during typical years.

On balance, life cycle costs pertain exclusively to sensor repair and maintenance, and available anecdotal evidence and personal observation suggests that those costs might well be zero over a 10-year period.

8.0 IMPLEMENTATION ISSUES

This project demonstrated the integrated multi-sensor geophysical approach for investigating archaeological sites, and *ArchaeoFusion*, a new software that was developed to serve as the technology (that is, the approaches') infusion tool.

8.1 INTEGRATED MULTI-SENSOR APPROACH

The integrated multi-sensor approach is based on the use of extant, commercially available geophysical sensors to provide information about the presence, nature, and distribution of subsurface features and other deposits at archaeological sites. For archaeological sites, intact features are often viewed as adequate evidence for integrity of deposits, and it is often assumed that the feature contents are likely to provide information important to history or prehistory (Criterion D). The traditional approach to evaluating a site's eligibility for the NRHP is based on hand excavation (often a grid of shovel tests and a few small test units). The result is that only a tiny percent of the site's subsurface is actually seen, and there is a very high likelihood of missing intact features. In the integrated multi-sensor approach, geophysical surveys are used to search for anomalies that may be associated with discrete features across much or all of a site. Excavation units can be targeted on representative or the promising anomalies (Hargrave 2006). The integrated multi-sensor geophysical approach thus provides much more reliable information about the presence/absence of features, reducing the likelihood of failing to protect significant sites as well as the risk of requiring training to avoid sites that actually have little scientific or cultural importance.

ArchaeoFusion

ArchaeoFusion is a new, user-friendly software that was developed by the CAST project team to make the benefits of the integrated multi-sensor approach more accessible to CRM personnel who are not (and may not want to become) geophysical experts. *ArchaeoFusion* can be used to process data from all of the major sensors used in the US (previously, it was necessary to have substantial expertise in several different software). *ArchaeoFusion* offers a number of approaches for integrating ("fusing") multiple data sets into a single image. Prior to *ArchaeoFusion*, data integration was restricted to overlaying an image map and a contour map, vectorized anomaly maps, or maps in several colors. None of these approaches were satisfactory, particularly for integrating more than two data sets. We have found that actual data fusion is a huge advantage for some sites and is not necessary at others. What is *always* useful, however, is overlaying maps to identify locations where multiple sensors detect anomalies. *ArchaeoFusion* facilitates this by treating the data from each sensor as a separate, georeferenced data layer whose color and transparency can be controlled by the user.

Processing and interpreting geophysical data is an intrinsically iterative process. The experienced practitioner typically has expectations based on experience about what processing sequences will work, but he or she then invariably tries many alternative approaches to optimize the image, i.e., to tease out low contrast anomalies, reduce clutter, etc. In older software, iterative processing required one to store variants in separate files, and to often do partial (even complete)

reprocessing to different approaches. *ArchaeoFusion* is designed to optimize and streamline iterative processing, allowing the user to alter parameters and rearrange the order of processing steps with no redundant effort. It also allows users to store processing sequences that have been found to be effective in the past, or that are suggested by colleagues or mentors.

8.2 Guidance Documents

The use of geophysics by US archaeologists has increased substantially in the past few years, and we are certain that *ArchaeoFusion* will accelerate that trend. Each year at professional conferences one sees presentations by "new "individuals who are clearly becoming geophysical experts. There is also a growing number—and need—for competent but not necessarily expert users. It is the current and future members of that second group that are the focus of this demonstration project.

The geophysical literature aimed primarily at archaeologists is also growing. This includes several methodological volumes and a number of case studies. We have found that the introductory-level methodological volumes provide a good introduction to the various techniques, conveying why archaeologists should consider adopting geophysics. What we found to be missing was a monograph that would guide CRM team leaders and their immediate supervisors in how to develop a competent in-house geophysical capability. To that end, Ernenwein and Hargrave wrote *Archaeological Geophysics for DoD Field Use: a Guide for New and Novice Users* (2007). It begins with a discussion of fundamental concepts like contrast, noise, clutter, data density, and resolution. These five concepts provide a basis for understanding why certain instruments work well at some sites and not others, why some features can be detected and others can't, and why some sites are good candidates for the integrated multi-sensor approach and others are not. The volume introduces each of the main methods, but focuses more than other technology overviews on a number of critical issues that CRM team leaders should consider *before* they purchase sensors:

- Estimating a site's suitability for geophysical survey
- Choosing suitable methods for particular sites and kinds of sites
- Selecting sensors (several choices are available for most methods)
- Designing a field strategy (survey design)
- Estimating time and cost factors
- Integrating geophysics into a regional program

We also recommend the following methodological overviews, all of which introduce readers to the capabilities of the various methods. Most or all of the examples included in these volumes are "success stories". The Ernenwein and Hargrave (2007) volume, if not unique, is unusual in frequently pointing out common errors and how they can be avoided (see also Kvamme 2006).

Remote Sensing in Archaeology: An Explicitly North American Perspective, edited by Jay K. Johnson (University of Alabama Press, Tuscaloosa, 2006).

Johnson worked with NASA geoarchaeologist Marco Giardino to establish a geophysical capability at the University of Mississippi. In preparation for this volume, they hosted an initial

meeting of the authors to develop a shared concept for the book. Virtually all of the authors have served as instructors in the NPS course (held at Los Adaes in 2009), and at that time, they made up the core group of archaeological geophysical experts in the US. Each author provides a practical overview of one of the techniques that he/she if best known for. Johnson's (2006) volume was the first that accorded substantial attention to ground truthing the results of geophysical surveys (Hargrave 2006).

Geophysical Surveys as Landscape Archaeology, by Kenneth Kvamme (American Antiquity 68(3):435-457, 2003). Kvamme is widely recognized as one of the academic leaders of archaeo-geophysics in the US. He led the SERDP project (RC-1263) that was the inspiration for this ESTCP demonstration project. This article ably illustrates the benefits of large area surveys using multiple sensors.

Seeing Beneath the Soil, by Anthony Clark (Batsford, London, 1996). Clark's work inspired several academic generations of geophysical archaeologists in the UK and Europe. We list this volume last only because it is more technical that those identified above (it may be too technical for new users who do not aspire to becoming experts). Several later volumes that were probably inspired by Clark's classic are also useful: *Revealing the Buried Past*, by Chris Gaffney and John Gater (Tempus Publishing, Ltd., Gloucestershire, UK) is less technical, whereas, *Handbook of Geophysics and Archaeology* by Alan Witten (Equinox Publishing, London) is somewhat more technical.

Throughout this report and elsewhere (Ernenwein and Hargrave 2007; Kvamme et al. 2006) we have emphasized the unique character of sites and their implications for the selection of methods. Despite this individuality, sites within particular areas and regions often share important soil, vegetation, and other characteristics, and this makes it important to read case studies relevant to one's own research area. While the number of case studies is growing, they are still too few relative to their importance to new and novice practitioners. While no guidelines for adequate reporting have yet been promulgated in the US, nearly all commercial surveys result in at least a map and brief letter report. One can sometimes get access to unpublished case studies (often accompanied by useful advice) by contacting experienced users.

8.3 Regulations

GPR sensors are categorized as ultra wideband (UWB) devices. The US Federal Communications Commission (FCC) regulates the amount of electromagnetic emissions that various devices can emit to prevent them from interfering with one another. In 2002, the FCC enacted regulations on the use of GPR in response to a growing concern that GPR antennas could interfere with certain equipment important to public safety, including aircraft radar, GPS and cell phone communications. GPR antennas working at frequencies below 960 MHz (including nearly all systems used for archaeology) were excluded from that requirement, as were devices in higher frequency ranges of 3.1 to 10.6 GHz. (Antennas used in pavement evaluation [1 to 2 GHz] were regulated, and that became a major concern for that industry). Later in July 2002 the FCC permitted the continued use of all existing GPR devices, and in February 2003, amended the regulations (Part 15) to also allow the use of new systems.

"FCC regulation 15.525(c) (updated in February 2007) requires users of GPR equipment to coordinate the use of their GPR equipment as described below:

(a) UWB imaging systems require coordination through the FCC before the equipment may be used. The operator shall comply with any constraints on equipment usage resulting from this coordination.

(b) The users of UWB imaging devices shall supply operational areas to the FCC Office of Engineering and Technology, which shall coordinate this information with the Federal Government through the National Telecommunications and Information Administration. The information provided by the UWB operator shall include the name, address and other pertinent contact information of the user, the desired geographical area(s) of operation, and the FCC ID number and other nomenclature of the UWB device. If the imaging device is intended to be used for mobile applications, the geographical area(s) of operation may be the state(s) or county(ies) in which the equipment will be operated. The operator of an imaging system used for fixed operation shall supply a specific geographical location or the address at which the equipment will be operated. This material shall be submitted to:

Frequency Coordination Branch, OET

Federal Communications Commission

445 12th Street, SW,

Washington, D.C. 20554

Attn: UWB Coordination

The form given on the following page is a suggested format for performing the coordination.

http://www.rjmcompany.com/GPR-ground%20penetrating-radar-manual.pdf

On balance, the GPR antennas used in archaeology are compliant with FCC regulations and do not pose a health and safety hazard. Purchasers should be certain to comply with FCC regulations concerning registration. Sample forms by one manufacturer are provided here as Figures 8-1 and 8-2.

Manufacturers of geophysical instruments are obviously highly motivated to comply with FCC regulations and to minimize the compliance actions (which appears to be submission of one form) of their customers. In our experience, most archaeological investigations on military installations occur in the training lands, far from concentrations of other electromagnetic systems. Prior to conducting geophysical surveys in immediate proximity to communications facilities, installation CRM personnel should convey their plans to the proper Point of Contact. Almost certainly, the greatest risk of electromagnetic interference will originate with sensor operators or their assistants who forget to turn off their cell phones.

Geophysical Survey Systems, Inc. 12 Industrial Way Tel 603.893.1109 • Fax 603-889-3984
Salem, NH 03079 www.geophysical.com • sales@geophysical.com

To whom it may concern:

This is to certify that electromagnetic radiation emissions from transducers (antenna with transmitting and receiving electronics) manufactured by Geophysical Survey Systems, Inc. (GSSI) DO NOT constitute a safety or health hazard to operating personnel. Emissions from GSSI transducers are far below the 10mW/cm² (100W/m²) level specified by the United States Occupational Safety and Health Administration (OSHA) regulations Paragraph 1910.97 states: "For normal environmental conditions and for incident electromagnetic frequencies from 10 MHz to 100 GHz, the radiation protection guide is10 mW/cm² (milliwatt per square centimeter) as averaged over any possible 0.1 hour period."

Emissions data using GPR SIR System-10, SIR-2, SIR-3, SIR-4, SIR-8, SIR-20, SIR-2000 and SIR-3000 (at the standard Pulse Repetition Frequency of 100 KHz) with the antenna Models listed and levels of Electromagnetic Radiation are specified herein:

Following is the average power density data at 5 cm and wide band. ANTENNA (MHz)	AVERAGE POWER DENSITY (mW/cm² @ 5 cm)	OSHA SPEC. (mW/cm²)
200	Less than 0.001	10
300	Less than 0.001	10
270	Less than 0.001	10
400	Less than 0.001	10
500	Less than 0.001	10
900	Less than 0.001	10
1000	Less than 0.001	10
1600	Less than 0.001	10
2000	Less than 0.001	10
2600	Less than 0.001	10
Terravision	Less than 0.001	10

Figure 8-1. Copy of a letter from Geophysical Survey Systems, Inc. documenting compliance with OSHA regulation Paragraph 1910.97 concerning emissions from GSSI transducers. Source: http://www.geophysical.com/Documentation/Other/GSSI-OSHACertificate.pdf

For U.S. Customers

Ground Penetrating Radar Coordination Notice and Equipment Registration

Note: This form is only for Domestic United States users. The Federal Communications Commission (FCC) requires that all users of GPR who purchased antennas after July 15th, 2002 register their equipment and areas of operation. If you have purchased any antennas after July 15th, 2002, you must fill out this form and fax or mail to the FCC.

Failure to do this is a violation of Federal law.

1. Date:

2. Company name:

3. Address:

4. Contact Information [contact name and phone number]:

5. Area of Operation [state(s)]:

6. Equipment Identification:

Brand Name: Geophysical Survey Systems, Inc.

Antenna Model No. (center frequency): *List all antennas being registered.*

Model	Center Frequency	FCC ID (QF7 Followed by Model Number

7. Receipt Date Of Equipment:

Fax this form to the FCC at: 202-418-1944

Or

Mail to:

Frequency Coordination Branch, OET

Federal Communications Commission

445 12th Street, SW

Washington, D.C. 20554

ATTN: UWB Coordination

Do not send this information to GSSI.

Figure 8-2. Form provided by GSSI for their customers to register antennas with the FCC. Source: http://www.geophysical.com/Documentation/Other/FCCRegistrationForm-GSSI.pdf

8.4 DECISION MAKING FACTORS AND END USER CONCERNS

Our discussion (in Section 7.3) of the costs and benefits of the integrated multi-sensor approach was, in places, necessarily somewhat conjectural. Budgetary issues made it necessary for all of our cost comparisons to be based on data from Los Adaes, the project demonstration site. Los Adaes is, by virtue of its history and visually compelling layout, a dramatic site. We intentionally chose such a site to arouse the interest of many CRM practitioners andDoD decision makers who might not otherwise consider using geophysics. Another advantage of Los Adaes is that substantial investigations were conducted there prior to our project. That work makes it easy to envisage, for example, how a traditional NRHP evaluation could require twice (or more) the volume of excavation conducted during our ground truthing. While fewDoD installations have 18th century Spanish forts, many have sites from other time periods of similar size, complexity, and management cost. On balance, our comparisons of estimated costs of traditional approaches versus use of the integrated multi-sensor approach are realistic and their implications are unambiguous.

Several important points warrant reiteration.

- The integrated multi-sensor geophysical approach to evaluating the NRHP eligibility of relatively complex archaeological sites is substantially more efficient than the traditional approach in terms of both costs and information return.
- Savings associated with the use of the integrated multi-sensor approach in a small number of NRHP evaluations of sites similar in complexity to Los Adaes would be adequate to establish a fully equipped in-house geophysical capability.
- The integrated multi-sensor approach to mitigating a relatively complex site by means of large scale data recovery is dramatically more efficient than a traditional approach in terms of both costs and information return.
- Savings associated with use of the integrated multi-sensor approach in *one* site mitigation like that described in Chapter 7 would be adequate to establish a fully equipped in-house geophysical capability.
- Establishing and using an in-house geophysical capability would allow an installation's CRM program to control the timing and level of effort in future NRHP evaluations, avoid ongoing costs associated with hiring consulting firms to evaluate sites (using either approach), and create an affordable option for mitigating sites that represent serious obstacles for military training and infrastructure expansion.

Informal conversations with numerous attendees at NPS classes over the years indicate that many CRM units would like to adopt geophysics but are not able to afford sensor purchase costs. The extent of previous investigations at Los Adaes makes it clear that the traditional approach to evaluating reasonably complex sites has very high labor costs. This is particularly true for sites where mitigation involves very extensive data recovery. The larger and more complex a site is, the greater the opportunity to use data on feature location derived from geophysical survey to reduce the amount of excavation needed. We do not suggest that the integrated multi-sensor approach should or will replace traditional excavation. Sites manifest as low-density artifact scatters are unlikely to include features but in some cases may have intact artifact concentrations,

thin lenses of sub-plow zone midden, etc. Those sites can best be evaluated using the traditional approach, even if the installation has an in-house geophysical capability.

Thoughtful answers to the following questions will help CRM personnel and program managers make decisions about adopting the integrated multi-sensor approach or continuing exclusively with the traditional approach at their own installation.

1) Does the installation include many sites not yet evaluated for NRHP eligibility that are likely to have discrete subsurface features?

   This can be answered by archaeologists with a substantial knowledge of the region. If the answer is yes, proceed to 2). If you remain uncertain about the answer and are still interested in geophysics, we suggest you contract for a partial geophysical survey of one or two of your larger, more complex sites to determine if features are present and can be detected before you invest in sensors.

2) Are dozens of your unevaluated sites relatively large (one ha or more) and complex (moderately abundant artifacts, evidence for several occupational components)? If yes, proceed to 3).

   Our cost analysis demonstrates that the integrated multi-sensor approach is substantially more cost effective than a traditional NRHP evaluation for large, complex sites. The ratio of benefits to costs decreases as one considers increasingly small, less complex sites.

3) Do many of those sites have vegetation that would permit geophysical survey without extensive clearing? Refer to Ernenwein and Hargrave (2007) for guidance on evaluating site suitability for geophysical survey.

4) Would funding circumstances permit the CRM program to invest in 2 or 3 sensors ($40,000 to $60,000) over the course of one or several years to establish an in-house capability in return for expected substantial decreases in future contracts to evaluate the NRHP status of sites? If yes, refer to Ernenwein and Hargrave (2007) for detailed guidance on selecting sensors. If not, consider contracting for a geophysical survey of several promising sites, and if results are positive, use them to bolster your rationale for an in-house geophysical capability.

5) Does the installation have at least a few large, complex sites that represent very serious obstacles to training or infrastructure expansion? The mitigation (by large scale data recovery) could offset the costs of establishing an in-house geophysical capability. An effective approach would be to hire an experienced practitioner to collect, process, and interpret the data while training installation personnel.

An in-house geophysical capability would not be cost effective for all installations. Those that have primarily small sites and/or sites that apparently have few discrete features (e.g., Fort Bragg, NC), very shallow rocky soil (e.g., Fort Leonard Wood, MO), or where effective work by the CRM program in past years has minimized limitations on training posed by archaeological sites might be best served by the traditional approach. Even installations that develop an in-house geophysical capability would probably still use the traditional approach for many small sites,

sites with dense vegetation, or heavy surface disturbance. Maximum cost effectiveness could be achieved by an experienced manager who learns when the integrated multi-sensor approach will yield its benefits, but who does not systematically apply it in all situations.

Figure 8-3 indicates that, as site size and complexity increase, so too do the cost benefits of the integrated multi-sensor approach. Mitigating Los Adaes represents only one point on the unit-less graph and it would fall on the upper right end of the line. Small, non-complex sites would offer less cost advantage. If one included the sensor costs, the integrated multi-sensor would not result in a positive cost benefit until a small number of relatively complex sites had been evaluated for NRHP eligibility, or one such site had been mitigated. No actual data are available, since Los Adaes was the only site considered. Installation personnel could generate a simple model more relevant to their own situation by considering the average cost per site for an NRHP evaluation and estimate how much they could reduce hand excavation. Installation personnel should also consider that the integrated multi-sensor approach makes the mitigation of sites whose presence is highly problematic economically feasible. We are not aware of an approach for calculating the costs associated with the need to avoid sites during military training, but those costs are certainly real, both in dollars and in loss of training realism.

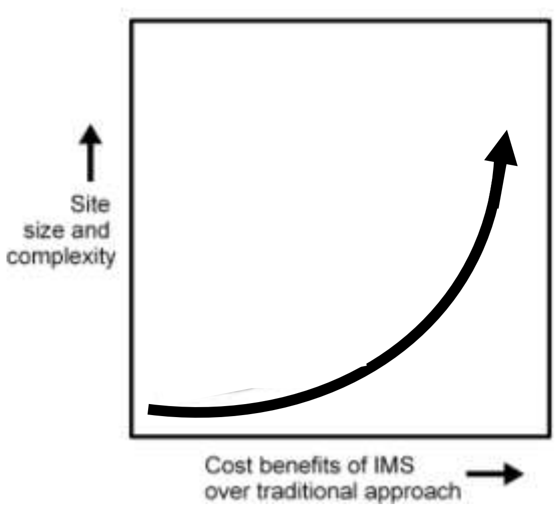


Figure 8-3. Graph showing the relationships between site size and complexity and the cost benefits of the integrated multi-sensor approach. Not based on actual data.

8.5 PROCUREMENT ISSUES

The purchase cost of *ArchaeoFusion* for non-DoD customers has yet to be determined. The software will be ready for distribution by the end of 2011. We are aware of no other procurement issues. All of the sensors used by archaeological practitioners in the US are commercially available (COTS).

8.6 REVISED TECHNOLOGY INFUSION PLAN

From its inception, this project's primary goal has been to transfer the integrated multi-sensor geophysical approach to the investigation of archaeological sites to DoD. The cost and information return benefits will be greatest at large installations with active training programs and numerous archaeological sites that either have not yet been evaluated for NRHP eligibility, or that are eligible but represent serious obstacles to military training, infrastructure expansion, or other military needs or activities. Cost savings achieved by use of this approach will be greatest for relatively large and complex sites.

Our original technology infusion strategy focused on demonstrating howDoD CRM programs could achieve the cost and performance benefits by means of a "direct" approach--purchasing sensors, training personnel, and integrating the approach into regular use. Unfortunately, this 5-year project has spanned a dark period in the nation's economy, and a full recovery is not yet in sight. Expected reductions in funds available for managing cultural resources may delay the direct adoption of the technology byDoD. Despite this situation, we envision at least two ways thatDoD installations could realize the cost and information benefits of the approach. In the recent past,DoD installations have often developed multi-year indefinite delivery indefinite quantity (IDIQ) contracts with CRM providers. Installations are increasingly using national IDIQ contracts with large firms (who sometimes partner with smaller, more specialized firms). While this shift may decrease an installation's potential to contract with some of the smaller, local firms they have used in the past, contracting with large firms may create more of an opportunity to adopt the integrated geophysical approach. The expectation of multi-year awards (IDIQ contracts often have the option to be continued for 5 years) might encourage larger firms to make the investment in the multiple sensors and staff training needed to adopt the integrated multi-sensor approach. Installation CRM programs could encourage this effort by requesting or, in carefully chosen situations, requiring use of the geophysics in evaluating and mitigating sites.

Unless they happen to have substantial experience in using geophysical methods, the installation personnel should consult with experienced geophysical practitioners associated with DoD research labs (e.g., ERDC), Corps of Engineer Districts, or trusted private sector consultants. (The authors can identify many such individuals and organizations). Important issues to be considered include the selection of installations and individual sites where geophysical methods are likely to be successful, and that are large enough to ensure the cost and information return benefits. Another important issue is the selection of primary and secondary instruments that are appropriate to the natural and cultural characteristics of installations and sites. Installation CRM personnel interested in the integrated multi-sensor approach should read the guidance document prepared by this project (Ernenwein and Hargrave 2007), which addresses these and other relevant issues. Installation personnel would also be wise to consult with their State Historic Preservation Office early in the process. Many SHPO personnel are not yet knowledgeable about geophysics, but awareness of its benefits relative to traditional archaeological approaches is steadily growing. SHPO personnel are likely to be particularly interested in the extent to which ground truthing will be used to verify or refute interpretations based on the geophysical survey results. Installation personnel could help SHPO reviewers gain confidence in the reliability of geophysics by including more ground truthing in their initial projects than might otherwise be required.

One issue that has frequently arisen in discussions about the adoption of geophysics in CRM is the concern that small firms would not be able to compete with larger companies that can afford to invest in multiple sensors and specialized personnel. One way to address this concern is to encourage SHPO reviewers to view the integrated geophysical approach as an alternative to—*not* a replacement of—traditional archaeological approaches. If both approaches are available, archaeologists will soon learn how to use the approach that will best achieve the short term goals of individual projects and the longer term goals of cost avoidance and increasing the potential for removing sites that represent obstacles to training by means of professionally responsible mitigation.

A second strategy for securing access to the integrated multi-sensor approach would be for multiple installations to share equipment and expertise. There may well be contractual or other bureaucratic restrictions on personnel stationed at (and paid by) one installation assisting in CRM activities at a second installation. Those limitations could probably be overcome with proper planning and coordination with Contracting Officers and appropriate managers. If so, installations could benefit from the expertise of other federal CRM employees for little more than the associated TDY costs. Representatives of the CRM programs at all of the participating installations should become familiar with the issues and information mentioned above, particularly the selection of sites amenable to the geophysical approach. All participating programs should assure themselves that the individuals who will collect, process, and interpret the geophysical data have acquired adequate training. Use of *ArchaeoFusion* can expedite that, but acquiring adequate expertise demands both interest and effort. Experienced DoD geophysical practitioners could help verify the competence of novice practitioners by reviewing their processed data, interpretations, and proposed ground truthing strategies.

To ensure the success of both of these strategies, the DoD CRM community must take care to avoid a mistake that has slowed the adoption of geophysics by US archaeologists. We should not expect the approach to be the proverbial "silver bullet" for the funding and other challenges that confront CRM. Cost and information return benefits will be realized by those who choose sites wisely; acquire a modest but adequate level of expertise; maintain both professional enthusiasm and skepticism; and who seek advice from, and share their successes and failures with colleagues. Using geophysics at sites that are not suitable; using inappropriate instruments or survey designs; allowing incompetent individuals to collect, process, and interpret data; and failing to develop ground truthing strategies that are well integrated with the geophysical survey and characteristics of the local archaeology have led numerous archaeologists to try geophysics *only once*. Careful reading of this project's guidance document (Ernenwein and Hargrave 2007) and consultation with competent mentors and colleagues can prevent nearly all failures.

To help insure that the adoption of the integrated multi-sensor geophysical approach is successful, we suggest that ESTCP consider several modest investments: 1) Sponsor web-based training courses in the use of *ArchaeoFusion*. In addition to working with the software, such courses could also include discussion of issues covered by the guidance document already referenced (Ernenwein and Hargrave 2007). 2) Sponsor 1-day classes at professional conferences such as the annual meetings of the Society for Historic Archaeology and Society for American Archaeology. Those organizations already offer a number of courses (in topics such as archaeological chemistry, Native American consultation, and the Section 106 process) each year immediately prior to or during their conferences. Prospective instructors are often already in

attendance, making additional costs modest. Such classes should be directed at both geophysical practitioners and SHPO and other agency personnel who need to be able to differentiate competent from incompetent geophysical applications. 3) Sponsor an informal vetting process, wherein experienced DoD geophysical practitioners work with trainees for a day or two in the field to ensure that they have achieved the basic knowledge and experience to conduct their own surveys. These practices will go a long way towards ensuring that the DoD CRM community will realize the benefits of the integrated multi-sensor approach.

Additional measures that will aid the adoption of the multi-sensor geophysical approach using *ArchaeoFusion* will be the free availability of the software to DoD personnel, and free time-limited *ArchaeoFusion* licenses for classrooms teaching geophysics. These combined with online classes may foster the adoption of the approach to a broad audience of CRM practitioners and young archaeologists who are still in school and that will soon enter the CRM workforce.

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APPENDIX A: POINTS OF CONTACT

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone Fax E-mail	Role in Project
Michael Hargrave	US Army, Engineer Research and Development Center, Construction Engineering Research Lab, Champaign, IL	(217) 373-5858 Michael.L.Hargrave@usace.army.mil	Project PI
Jackson Cothren	Center For Advanced Spatial Technologies, University of Arkansas, Fayetteville	(479) 575-5421 jcothren@cast.uark.edu	Matlab Programming and Algorithm Development
Eileen Ernenwein	Center For Advanced Spatial Technologies, University of Arkansas, Fayetteville	eernenw@cast.uark.edu	Geophysics Expert, *ArchaeoFusion* Expert, Algorithm Development
William Johnston	Center For Advanced Spatial Technologies, University of Arkansas, Fayetteville	wgj@cast.uark.edu	Java and Matlab Programming, Algorithm and GUI Development

APPENDIX B: ASSESSMENT 2 ONLINE SURVEY RESULTS

The following is a summary report of the Assessment 2 online survey, followed by the individual survey results from each of the 14 participants.

Response Summary

Total Started Survey: 14

Total Completed Survey: 14 (100%)

PAGE: *ARCHAEOFUSION* USERS SURVEY

1. In regards to archaeological geophysics in general (regardless of software): multiple surveys, even when not integrated, provide more useful information than single sensor surveys.							
	answered question						14
	skipped question						0
	Strongly Disagree	Disagree	Neutral	Agree	**Strongly Agree**	Rating Average	Response Count
rate :	0.0% (0)	0.0% (0)	0.0% (0)	35.7% (5)	**64.3% (9)**	4.64	14

2. In regards to archaeological geophysics in general (regardless of software), data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc) increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets.							
	answered question						14
	skipped question						0
	Strongly Disagree	Disagree	Neutral	Agree	**Strongly Agree**	Rating Average	Response Count
rate:	0.0% (0)	0.0% (0)	0.0% (0)	35.7% (5)	**64.3% (9)**	4.64	14

3. *ArchaeoFusion* allows users to effectively integrate data from multiple sensors (i.e. overlays, translucent overlays, band calculator, principle components analysis, and k-means cluster analysis).							
	answered question						14
	skipped question						0
	Strongly	Disagree	Neutral	**Agree**	Strongly	Rating	Response

3. *ArchaeoFusion* allows users to effectively integrate data from multiple sensors (i.e. overlays, translucent overlays, band calculator, principle components analysis, and k-means cluster analysis).							
	Disagree				Agree	Average	Count
rate:	0.0% (0)	0.0% (0)	14.3% (2)	**64.3% (9)**	21.4% (3)	4.07	14

4. Data from all major sensor types can be adequately processed using *ArchaeoFusion* alone.							
	answered question						14
	skipped question						0
	Strongly Disagree	Disagree	Neutral	**Agree**	Strongly Agree	Rating Average	Response Count
rate:	0.0% (0)	28.6% (4)	28.6% (4)	**35.7% (5)**	7.1% (1)	3.21	14

5. In comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers (i.e. GPR, EMI, magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. (metadata is the information about your data, such as what instrument was used to collect it, the start corner and direction for the survey, etc.).							
	answered question						14
	skipped question						0
	Strongly Disagree	Disagree	**Neutral**	Agree	Strongly Agree	Rating Average	Response Count
rate:	0.0% (0)	0.0% (0)	**50.0% (7)**	35.7% (5)	14.3% (2)	3.64	14

6. *ArchaeoFusion* preserves data resolution. (meaning, that when you are finished processing your data, you can always revert to the original data with the original data density).							
	answered question						14
	skipped question						0
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Rating Average	Response Count
rate:	0.0% (0)	0.0% (0)	7.1% (1)	42.9%	50.0% (7)	4.43	14

6. *ArchaeoFusion* preserves data resolution. (meaning, that when you are finished processing your data, you can always revert to the original data with the original data density).							
				(6)			

7. Data processing using *ArchaeoFusion* is faster and easier than processing using other COTS (commercial off-the-shelf) software.							
	answered question						14
	skipped question						0
	Strongly Disagree	Disagree	**Neutral**	**Agree**	Strongly Agree	Rating Average	Response Count
rate:	0.0% (0)	7.1% (1)	**35.7% (5)**	**35.7% (5)**	21.4% (3)	3.71	14

8. Ground-truthing (test excavations to evaluate interpretation of geophysical data) enhances the usefulness of geophysical data.							
	answered question						14
	skipped question						0
	Strongly Disagree	Disagree	Neutral	Agree	**Strongly Agree**	Rating Average	Response Count
rate:	0.0% (0)	0.0% (0)	14.3% (2)	14.3% (2)	**71.4% (10)**	4.57	14

9. Please comment on the benefits of *ArchaeoFusion* and describe any shortcomings that you perceive.		
	answered question	11
	skipped question	3
		Response Count
		11

10. If you would like a free 1-year license of *ArchaeoFusion* and have completed all questions in this survey, please enter your name here.		
	answered question	14

10. If you would like a free 1-year license of *ArchaeoFusion* and have completed all questions in this survey, please enter your name here.		
	skipped question	0
		Response Count
		14

Individual Respondent Results
Respondent 1 of 14

1. In regards to archaeological geophysics in general (regardless of software): multiple surveys, even when not integrated, provide more useful information than single sensor surveys.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

2. In regards to archaeological geophysics in general (regardless of software), data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc) increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

3. *ArchaeoFusion* allows users to effectively integrate data from multiple sensors (i.e. overlays, translucent overlays, band calculator, principle components analysis, and k-means cluster analysis).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

4. Data from all major sensor types can be adequately processed using *ArchaeoFusion* alone.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

5. In comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers (i.e. GPR, EMI, magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. (metadata is the information about your data, such as what instrument was used to collect it, the start corner and direction for the survey, etc.).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

6. *ArchaeoFusion* preserves data resolution. (meaning, that when you are finished processing your data, you can always revert to the original data with the original data density).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

7. Data processing using *ArchaeoFusion* is faster and easier than processing using other COTS (commercial off-the-shelf) software.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

8. Ground-truthing (test excavations to evaluate interpretation of geophysical data) enhances the usefulness of geophysical data.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

9. Please comment on the benefits of *ArchaeoFusion* and describe any shortcomings that you perceive.

No Response

Respondent 2 of 14

1. In regards to archaeological geophysics in general (regardless of software): multiple surveys, even when not integrated, provide more useful information than single sensor surveys.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

2. In regards to archaeological geophysics in general (regardless of software), data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc) increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

3. *ArchaeoFusion* allows users to effectively integrate data from multiple sensors (i.e. overlays, translucent overlays, band calculator, principle components analysis, and k-means cluster analysis).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

4. Data from all major sensor types can be adequately processed using *ArchaeoFusion* alone.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:		X			

5. In comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers (i.e. GPR, EMI, magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. (metadata is the information about your data, such as what instrument was used to collect it, the start corner and direction for the survey, etc.).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

6. *ArchaeoFusion* preserves data resolution. (meaning, that when you are finished processing your data, you can always revert to the original data with the original data density).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

7. Data processing using *ArchaeoFusion* is faster and easier than processing using other COTS (commercial off-the-shelf) software.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

8. Ground-truthing (test excavations to evaluate interpretation of geophysical data) enhances the usefulness of geophysical data.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

9. Please comment on the benefits of *ArchaeoFusion* and describe any shortcomings that you perceive.

No Response

Respondent 3 of 14

1. In regards to archaeological geophysics in general (regardless of software): multiple surveys, even when not integrated, provide more useful information than single sensor surveys.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

2. In regards to archaeological geophysics in general (regardless of software), data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc) increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

3. *ArchaeoFusion* allows users to effectively integrate data from multiple sensors (i.e. overlays, translucent overlays, band calculator, principle components analysis, and k-means cluster analysis).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

4. Data from all major sensor types can be adequately processed using *ArchaeoFusion* alone.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

5. In comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers (i.e. GPR, EMI, magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. (metadata is the information about your data, such as what instrument was used to collect it, the start corner and direction for the survey, etc.).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

6. *ArchaeoFusion* preserves data resolution. (meaning, that when you are finished processing your data, you can always revert to the original data with the original data density).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

7. Data processing using *ArchaeoFusion* is faster and easier than processing using other COTS (commercial off-the-shelf) software.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

8. Ground-truthing (test excavations to evaluate interpretation of geophysical data) enhances the usefulness of geophysical data.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

9. Please comment on the benefits of *ArchaeoFusion* and describe any shortcomings that you perceive.

I have no idea what *ArchaeoFusion* is, no one has offered to let me try it. I have heard some things about it from Mike Hargrave, thats all.

Respondent 4 of 14

1. In regards to archaeological geophysics in general (regardless of software): multiple surveys, even when not integrated, provide more useful information than single sensor surveys.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

2. In regards to archaeological geophysics in general (regardless of software), data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc) increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

3. *ArchaeoFusion* allows users to effectively integrate data from multiple sensors (i.e. overlays, translucent overlays, band calculator, principle components analysis, and k-means cluster analysis).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

4. Data from all major sensor types can be adequately processed using *ArchaeoFusion* alone.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

5. In comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers (i.e. GPR, EMI, magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. (metadata is the information about your data, such as what instrument was used to collect it, the start corner and direction for the survey, etc.).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

6. *ArchaeoFusion* preserves data resolution. (meaning, that when you are finished processing your data, you can always revert to the original data with the original data density).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

7. Data processing using *ArchaeoFusion* is faster and easier than processing using other COTS (commercial off-the-shelf) software.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

8. Ground-truthing (test excavations to evaluate interpretation of geophysical data) enhances the usefulness of geophysical data.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

9. Please comment on the benefits of *ArchaeoFusion* and describe any shortcomings that you perceive.

The main benefit of *ArchaeoFusion* is that it gives the user the ability to integrate data multiple geophysical data types using a straight-forward and user-friendly interface. Before this product, I was using proprietary software, surfer, IDRISI, and other GIS software to open, transform, analyze data from each type of sensor (GPR, gradiometer, resistance) separately. I would then have to use GIS software to assemble the data into a single map, having to do some additional "tweaking." In the few months I have been using *ArchaeoFusion*, I have saved dozens of hours in analysis because the program performs all of these operations simultaneously. It has become an invaluable part of my research, and I will recommend it to my colleagues. The main shortcoming in the program is the GPR analytical module. This module is functional and it does perform the necessary operations, but it is much more cumbersome to use than software like GPR Slice. Importing GPR data is much more involved than the other sensor types, and I found myself a bit confused at the various choices one has when importing. Aesthetically, this module is also a bit bare bones, especially the "3D cube" function.

Respondent 5 of 14

1. In regards to archaeological geophysics in general (regardless of software): multiple surveys, even when not integrated, provide more useful information than single sensor surveys.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

2. In regards to archaeological geophysics in general (regardless of software), data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc) increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

3. *ArchaeoFusion* allows users to effectively integrate data from multiple sensors (i.e. overlays, translucent overlays, band calculator, principle components analysis, and k-means cluster analysis).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

4. Data from all major sensor types can be adequately processed using *ArchaeoFusion* alone.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

5. In comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers (i.e. GPR, EMI, magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. (metadata is the information about your data, such as what instrument was used to collect it, the start corner and direction for the survey, etc.).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

6. *ArchaeoFusion* preserves data resolution. (meaning, that when you are finished processing your data, you can always revert to the original data with the original data density).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

7. Data processing using *ArchaeoFusion* is faster and easier than processing using other COTS (commercial off-the-shelf) software.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

8. Ground-truthing (test excavations to evaluate interpretation of geophysical data) enhances the usefulness of geophysical data.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

9. Please comment on the benefits of *ArchaeoFusion* and describe any shortcomings that you perceive.

I haven't had the ability to fully investigate the software, what I have noticed thus far is that it is user friendly.

Respondent 6 of 14

1. In regards to archaeological geophysics in general (regardless of software): multiple surveys, even when not integrated, provide more useful information than single sensor surveys.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

2. In regards to archaeological geophysics in general (regardless of software), data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc) increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

3. *ArchaeoFusion* allows users to effectively integrate data from multiple sensors (i.e. overlays, translucent overlays, band calculator, principle components analysis, and k-means cluster analysis).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

4. Data from all major sensor types can be adequately processed using *ArchaeoFusion* alone.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

5. In comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers (i.e. GPR, EMI, magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. (metadata is the information about your data, such as what instrument was used to collect it, the start corner and direction for the survey, etc.).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

6. *ArchaeoFusion* preserves data resolution. (meaning, that when you are finished processing your data, you can always revert to the original data with the original data density).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

7. Data processing using *ArchaeoFusion* is faster and easier than processing using other COTS (commercial off-the-shelf) software.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

8. Ground-truthing (test excavations to evaluate interpretation of geophysical data) enhances the usefulness of geophysical data.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

9. Please comment on the benefits of *ArchaeoFusion* and describe any shortcomings that you perceive.

I represent a local community based archaeological group. Naturally we have limited funding and can only afford what is really needed. We specialise in remote sensing, in particular the use of kite aerial photography and the results can be incorporated with earth resistance (216M). I use *ArchaeoFusion* to process my basic earth resistance data and hope to combine it with our aerial data. This will form visible spectrum, infra-red, ultraviolet and thermal imaging data. Together this could form a powerful data set, but as yet we have yet to combine them all. I find *ArchaeoFusion* very useful, but do not think we would be able to purchase a full version, as this would be beyond our means and purpose.

Respondent 7 of 14

1. In regards to archaeological geophysics in general (regardless of software): multiple surveys, even when not integrated, provide more useful information than single sensor surveys.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

2. In regards to archaeological geophysics in general (regardless of software), data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc) increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

3. *ArchaeoFusion* allows users to effectively integrate data from multiple sensors (i.e. overlays, translucent overlays, band calculator, principle components analysis, and k-means cluster analysis).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

4. Data from all major sensor types can be adequately processed using *ArchaeoFusion* alone.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:		X			

5. In comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers (i.e. GPR, EMI, magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. (metadata is the information about your data, such as what instrument was used to collect it, the start corner and direction for the survey, etc.).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

6. *ArchaeoFusion* preserves data resolution. (meaning, that when you are finished processing your data, you can always revert to the original data with the original data density).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

7. Data processing using *ArchaeoFusion* is faster and easier than processing using other COTS (commercial off-the-shelf) software.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:		X			

8. Ground-truthing (test excavations to evaluate interpretation of geophysical data) enhances the usefulness of geophysical data.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

9. Please comment on the benefits of *ArchaeoFusion* and describe any shortcomings that you perceive.

It was difficult to evaluate the software since it does not seem to be entirely functional. The most obvious problems seem to be: The survey display control buttons (difference; show filter; etc...) do not seem to function, or do so very inconsistently. Because of this [I surmise] data processing appears to have no effect (except on unpredictable and irreproducible occasions). In other instances, operations attempted with reasonable parameters end with "Operation ______ failed to produce a result!" or sometimes with a runtime error that crashes *ArchaeoFusion*. I am using the most recent version of *ArchaeoFusion* on hardware and OS that should be up to spec. Several conversations with Bill were not able to resolve my problems. I think that the goal of the project to create a comprehensive package to integrate, process, and analyze different classes of data is a very important one. I also think that it has (or is intended to have) a very good set of features for data processing and visualization. I like the concept of preserving original data, although I wonder whether that might become a problem with very large datasets. The 3D rendering is neat, but I don't think that real-time rendering is really super-useful. I did not try rendering any large datasets in 3D, but I suspect it might pace some pretty serious demands on the system. In my experience, 2D rendering is generally more appropriate for visualizing archaeological patterning, and where 3D views are to be constructed, I would generally be satisfied with a static image. As an analogy, I sometimes use Voxler for 3D visualization of GPR data, animations, etc. It's good for making flashy-looking presentations, but I've never really found it to be particularly useful for serious analysis. I have noticed also that real-time 3D rendering in Voxler is very resource-intensive, and very limited in the size and resolution of datasets that can be handled. I think *ArchaeoFusion* could potentially be an excellent tool, and I would be interested in trying it again if it can be brought to a useful level of functionality.

Respondent 8 of 14

1. In regards to archaeological geophysics in general (regardless of software): multiple surveys, even when not integrated, provide more useful information than single sensor surveys.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

2. In regards to archaeological geophysics in general (regardless of software), data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc) increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

3. *ArchaeoFusion* allows users to effectively integrate data from multiple sensors (i.e. overlays, translucent overlays, band calculator, principle components analysis, and k-means cluster analysis).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

4. Data from all major sensor types can be adequately processed using *ArchaeoFusion* alone.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

5. In comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers (i.e. GPR, EMI, magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. (metadata is the information about your data, such as what instrument was used to collect it, the start corner and direction for the survey, etc.).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

6. *ArchaeoFusion* preserves data resolution. (meaning, that when you are finished processing your data, you can always revert to the original data with the original data density).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

7. Data processing using *ArchaeoFusion* is faster and easier than processing using other COTS (commercial off-the-shelf) software.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

8. Ground-truthing (test excavations to evaluate interpretation of geophysical data) enhances the usefulness of geophysical data.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

9. Please comment on the benefits of *ArchaeoFusion* and describe any shortcomings that you perceive.

Many thanks to you for sharing what a nice software and sample data .As a new users and for the people which start new about *ArchaeoFusion* studies, it is really educative and useful. All the best.

Respondent 9 of 14

1. In regards to archaeological geophysics in general (regardless of software): multiple surveys, even when not integrated, provide more useful information than single sensor surveys.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

2. In regards to archaeological geophysics in general (regardless of software), data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc) increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

3. *ArchaeoFusion* allows users to effectively integrate data from multiple sensors (i.e. overlays, translucent overlays, band calculator, principle components analysis, and k-means cluster analysis).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

4. Data from all major sensor types can be adequately processed using *ArchaeoFusion* alone.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

5. In comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers (i.e. GPR, EMI, magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. (metadata is the information about your data, such as what instrument was used to collect it, the start corner and direction for the survey, etc.).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

6. *ArchaeoFusion* preserves data resolution. (meaning, that when you are finished processing your data, you can always revert to the original data with the original data density).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

7. Data processing using *ArchaeoFusion* is faster and easier than processing using other COTS (commercial off-the-shelf) software.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

8. Ground-truthing (test excavations to evaluate interpretation of geophysical data) enhances the usefulness of geophysical data.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

9. Please comment on the benefits of *ArchaeoFusion* and describe any shortcomings that you perceive.

No Response

Respondent 10 of 14

1. In regards to archaeological geophysics in general (regardless of software): multiple surveys, even when not integrated, provide more useful information than single sensor surveys.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

2. In regards to archaeological geophysics in general (regardless of software), data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc) increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

3. *ArchaeoFusion* allows users to effectively integrate data from multiple sensors (i.e. overlays, translucent overlays, band calculator, principle components analysis, and k-means cluster analysis).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

4. Data from all major sensor types can be adequately processed using *ArchaeoFusion* alone.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

5. In comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers (i.e. GPR, EMI, magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. (metadata is the information about your data, such as what instrument was used to collect it, the start corner and direction for the survey, etc.).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

6. *ArchaeoFusion* preserves data resolution. (meaning, that when you are finished processing your data, you can always revert to the original data with the original data density).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

7. Data processing using *ArchaeoFusion* is faster and easier than processing using other COTS (commercial off-the-shelf) software.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

8. Ground-truthing (test excavations to evaluate interpretation of geophysical data) enhances the usefulness of geophysical data.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

9. Please comment on the benefits of *ArchaeoFusion* and describe any shortcomings that you perceive.

I used *ArchaeoFusion* briefly, but ran into problems trying to process data (getting errors from the matlab substrate). I processed gradiometer data I collected, and aside from the problems I encountered in processing the data using certain tool processes, I found the software fairly easy to use. I think it would behoove the designer to simplify the coordinate/GPS system used to georeference the data together. I found it to be somewhat confusing, and prefer ArcGIS 10.

Respondent 11 of 14

1. In regards to archaeological geophysics in general (regardless of software): multiple surveys, even when not integrated, provide more useful information than single sensor surveys.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

2. In regards to archaeological geophysics in general (regardless of software), data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc) increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

3. *ArchaeoFusion* allows users to effectively integrate data from multiple sensors (i.e. overlays, translucent overlays, band calculator, principle components analysis, and k-means cluster analysis).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

4. Data from all major sensor types can be adequately processed using *ArchaeoFusion* alone.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

5. In comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers (i.e. GPR, EMI, magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. (metadata is the information about your data, such as what instrument was used to collect it, the start corner and direction for the survey, etc.).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

6. *ArchaeoFusion* preserves data resolution. (meaning, that when you are finished processing your data, you can always revert to the original data with the original data density).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

7. Data processing using *ArchaeoFusion* is faster and easier than processing using other COTS (commercial off-the-shelf) software.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

8. Ground-truthing (test excavations to evaluate interpretation of geophysical data) enhances the usefulness of geophysical data.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

9. Please comment on the benefits of *ArchaeoFusion* and describe any shortcomings that you perceive.

I have been using *ArchaeoFusion* to process mag and EM data. I especially like how easy it is to overlay multiple surveys. When running a large stack of operations, it would be nice to have a progress bar, letting you know that it's still thinking.

Respondent 12 of 14

1. In regards to archaeological geophysics in general (regardless of software): multiple surveys, even when not integrated, provide more useful information than single sensor surveys.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

2. In regards to archaeological geophysics in general (regardless of software), data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc) increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

3. *ArchaeoFusion* allows users to effectively integrate data from multiple sensors (i.e. overlays, translucent overlays, band calculator, principle components analysis, and k-means cluster analysis).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

4. Data from all major sensor types can be adequately processed using *ArchaeoFusion* alone.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:		X			

5. In comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers (i.e. GPR, EMI, magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. (metadata is the information about your data, such as what instrument was used to collect it, the start corner and direction for the survey, etc.).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

6. *ArchaeoFusion* preserves data resolution. (meaning, that when you are finished processing your data, you can always revert to the original data with the original data density).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

7. Data processing using *ArchaeoFusion* is faster and easier than processing using other COTS (commercial off-the-shelf) software.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

8. Ground-truthing (test excavations to evaluate interpretation of geophysical data) enhances the usefulness of geophysical data.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

9. Please comment on the benefits of *ArchaeoFusion* and describe any shortcomings that you perceive.

This program has the potential to greatly enhance the ways in which many of us analyze, interpret, and present geophysical data, and is clearly valuable to novices and experienced geophysical archaeologists alike. It doesn’t just make it simpler to do more with different data sets: after data are processed, the available options actually encourage the user to try out different ways of combining data sets to see how they compare. With some understanding of how each technique works and what the measurements represent, users should be able to go far beyond simply identifying patterns and shapes, and be able to make intelligent statements about the nature of the causative features. Traditionally, I have resorted to simple image overlay options in GIS or graphics packages in order to compare and analyze my data. I then produced separate interpretations for each data set, before overlaying these for comparison. Therefore the option to directly compare data beyond simple overlays, using mathematical and statistical combinations, opens up new avenues for exploring and better understanding the data I’ve collected. It is also extremely welcome to have one package that can cope with processing data from a variety of sources. I

have taught a number of undergraduate and graduate archaeological prospection courses in North America and the UK, and when it comes to the data processing and display sections, it is always a challenge to introduce students to a suite of new programs in the time available – and the students always enquire why a single program doesn't exist. It appears that *ArchaeoFusion* could solve all our problems! Interface comments: One simple feature I really like is the "mouse controls". I often end up working with data in airports or other places where my laptop really is just on my lap, and so it is not possible to use a mouse. Finding these buttons brought a smile to my face! I also appreciate how easily the grid assembly / master grid can be accessed and edited. (That said, I am actually having some problems correctly combining/displaying data, both for the demo samples and my own data. Once imported, the thumbnail for each constituent grid square is displayed correctly in the "Survey Tool" window and I can place them all correctly to create the composite. However, after "Finishing" this and returning to the Data Viewing Space, the displayed composite is made up of only one square, repeated throughout. I've been able to change which square this is, but not get more than one square to display at one time! Either I'm doing something wrong or there's a glitch somewhere…) After a little time gaining familiarity, the Survey List is quite a useful tool to work with, (although I did initially expect the data 'on top' of the list to be displayed 'on top'… I soon learnt!) The display range (display contrast slider) is taking a little more time to get accustomed to. Firstly, it was not immediately clear whether values are s.d. or absolute - although this is stated in the manual. Personally I prefer the option to display my data between absolute values, but I must say I like the ability in AF to type in values. I am also finding it a little odd to work with the range displayed on the left, the "colormap" upper right, and the relevant distribution graph some distance below. If the displayed colormap could be directly correlated to the distribution graphs (or vice versa), I'd find it more useful if the two were closer together so that I can readily see which color is positive/negative, and how the values relate to the data for rapid understanding. Whilst not necessary for integrating data, I do value the option to display data in the "older" traceplot style, as this can be a useful part of interpreting results, especially magnetometer data. I may have missed it, but is it possible to display different data sets concurrently but using different colormaps? Sometimes it can be desirable to different results with black as high/positive and white as low/negative (e.g. when combining mag and res, since a ditch may be a positive magnetic anomaly and a low resistance response). Of course, AF does offer a solution here, as this can be achieved by using the Calculator to invert a data set and displaying it this way! Many of the windows I open up are slightly too small to display all the buttons and/or they extend just off the bottom of the screen. Neither are serious problems, but with repeated use and having to move and resize them, I could see this as a minor annoyance. (Some) processing comments: Clipping: appears to work fine, but it could be useful to specify whether the units here are s.d. or absolute. When destaggering, what does AF fill the gaps with? Are these values calculated from adjacent readings or is it the survey mean value? ZMT: Whilst it is unfortunate that many magnetometer data sets require some form of destriping, I find that ZMT is not always ideal or appropriate. For Bartington data, the 1m sensor separation results in more geological information being included in the results, with the result that the mean/median/mode of each line is not necessarily zero; therefore applying such a function produces unsightly grid edge discontinuities. One solution is a "sensor destripe" that I developed and was incorporated into ArcheoSurveyor, although this is still not perfect and could be improved on! I would certainly encourage AF to include thresholds for applying ZMT to reduced the effect of extreme ferrous responses. Clipping prior to ZMT helps, but is not always sufficient. A devoted "Interpolation" function would be welcome when it is fully developed. Personally I find the existing resampling & smoothing approach a little heavier than I would like, even if it does produce a prettier picture… When running the PCA, the resulting band names include time-slice details, e.g. 0-4ns, which is a little misleading since I assume that they are no longer relevant. Can/should this be altered? I sometimes could not get either the Despike or Mean Profile Filter functions to work on the demo MS and conductivity data sets, despite trying a number of settings. Initially I thought that this was because the surveys had been edited to shift them south by 1m, but moving them back prior to running the operation also produced an "ALERT!!!!" They did work, however, after loading the project again, so I assume this was a minor matlab glitch? In fact, in the process of doing this, I discovered that choosing "Cancel" instead of "Finished" after moving (nudging) a survey area in Survey Edit still results in the data being shifted. On occasion a process seemed to stall (or at least take 5-10 minutes). Since these otherwise took a fraction of a second (e.g. low pass (Gaussian) filter, or standardize), I am not sure what the issue was. Is there a way to cancel a process in such situations? Sometimes this required restarting AF, but other times I found it worked itself out if I left it alone! Other remarks: Of course, as the demonstration data highlighted, spatial accuracy in data collection is of crucial importance if different results are to be combined. Even with the ability to shift grids in the x and y directions so that the anomalies match, this may not be sufficient or even necessarily correct. At present I employ both Geoplot and ArcheoSurveyor to use aspects that each does best, and then a different package for GPR processing, all before combining images in a

GIS. *ArchaeoFusion* certainly has the potential to cut out programs and steps in things I already do, but if I'm honest, at present I see it as an additional program that I'd like to use to effectively combine data after I've processed it elsewhere. Admittedly, this is probably partly due to my familiarity with other software compared with AF, but processes such as zero mean/median traverse and interpolation are particular functions that I use most commonly, and at present I prefer the results I obtain using other programs. I can certainly expand on any of the comments I've made here and would be happy to do so. With further use and the ability to properly import my own data into AF, I hope to continue to provide feedback on this exciting new software package!

Respondent 13 of 14

1. In regards to archaeological geophysics in general (regardless of software): multiple surveys, even when not integrated, provide more useful information than single sensor surveys.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

2. In regards to archaeological geophysics in general (regardless of software), data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc) increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

3. *ArchaeoFusion* allows users to effectively integrate data from multiple sensors (i.e. overlays, translucent overlays, band calculator, principle components analysis, and k-means cluster analysis).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

4. Data from all major sensor types can be adequately processed using *ArchaeoFusion* alone.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:		X			

5. In comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers (i.e. GPR, EMI, magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. (metadata is the information about your data, such as what instrument was used to collect it, the start corner and direction for the survey, etc.).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

6. *ArchaeoFusion* preserves data resolution. (meaning, that when you are finished processing your data, you can always revert to the original data with the original data density).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

7. Data processing using *ArchaeoFusion* is faster and easier than processing using other COTS (commercial off-the-shelf) software.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

8. Ground-truthing (test excavations to evaluate interpretation of geophysical data) enhances the usefulness of geophysical data.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

9. Please comment on the benefits of *ArchaeoFusion* and describe any shortcomings that you perceive.

Excellent to have a single platform for integrating the most commonly used sensors in archaeological geophysics. Also a very significant contribution is the procedures for combining/fusing data. More development of these methods (in archaeology generally as well as in *ArchaeoFusion* specifically) would be very welcome across the community. Certain processing procedures (especially for GPR) can be done more effectively in dedicated software packages. I would also like to see more export functions (e.g., export data as txt, grd, or other file formats) to be able to use the data in other packages. As I understand it, *ArchaeoFusion* only supports exporting in GeoTiff format.

Respondent 14 of 14

1. In regards to archaeological geophysics in general (regardless of software): multiple surveys, even when not integrated, provide more useful information than single sensor surveys.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

2. In regards to archaeological geophysics in general (regardless of software), data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc) increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

3. *ArchaeoFusion* allows users to effectively integrate data from multiple sensors (i.e. overlays, translucent overlays, band calculator, principle components analysis, and k-means cluster analysis).

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rate:					X

4. Data from all major sensor types can be adequately processed using *ArchaeoFusion* alone.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:			X		

5. In comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers (i.e. GPR, EMI, magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. (metadata is the information about your data, such as what instrument was used to collect it, the start corner and direction for the survey, etc.).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:				X	

6. *ArchaeoFusion* preserves data resolution. (meaning, that when you are finished processing your data, you can always revert to the original data with the original data density).

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

7. Data processing using *ArchaeoFusion* is faster and easier than processing using other COTS (commercial off-the-shelf) software.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

8. Ground-truthing (test excavations to evaluate interpretation of geophysical data) enhances the usefulness of geophysical data.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
rate:					X

9. Please comment on the benefits of *ArchaeoFusion* and describe any shortcomings that you perceive.

I found *ArchaeoFusion* very useful as I was able to much more effectively analyze my project data that I had previously been unable to easily compare using more conventional means. I feel that this program will facilitate the use of geophysical data in archeological investigations by making it easier to manipulate and interpret.

APPENDIX C: EVALUATION INSTRUCTIONS FOR *ARCHAEOFUSION* ASSESSMENT 1

ArchaeoFusion Software Evaluation

Part I: Objective 1. The case for using multiple Geophysical Methods

Claim: Multiple geophysical methods are usually better than one method alone, and *ArchaeoFusion* allows you to accomplish that more easily because it can handle all of the major data types (GPR, magnetometry, resistivity, and EM). The goal of this part is to simply show that multiple datasets provide more information that single datasets, even if they are not integrated together for the interpretation.

What you need:

- Processed Los Adaes Data. I have chosen only one 20 x 20 m survey tile so you don't have to spend too much time on this.
- Site Background information: Los Adaes is a Spanish military post, mission, and settlement located in northwest Louisiana. It was chosen as the demonstration site for this ESTCP project, and was the site of the 2009 National Park Service Archaeological Prospection.

Deliverables:

1) For each survey (Resistivity, Conductivity, Magnetic Susceptibility, Magnetometry, and Ground-penetrating radar slice 5, 16-20 ns), identify and number all anomalies using outlines or lines. Report which anomalies are interpreted to be cultural features and which are probably not cultural features. Give the final count of (a) all anomalies, (b) cultural feature anomalies, and (c) non-feature anomalies.
2) Using *ArchaeoFusion*, examine each anomaly previously identified and report whether the anomaly occurs in other datasets, and if so which ones. A table such as the following is suggested (one for each datasets). The "total" column gives the total number of other datasets in which the same or similar anomaly was found.

Resistivity Anomalies

Anomaly #	feature?	in mag?	in MS?	in Cond?	in GPR	total
1	Y			x	x	2
2	N					0
3	Y	x				1

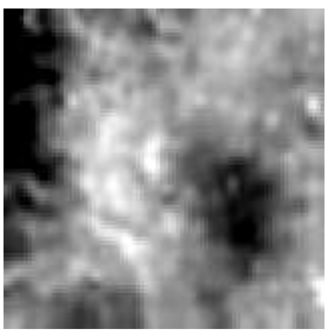
Instructions:

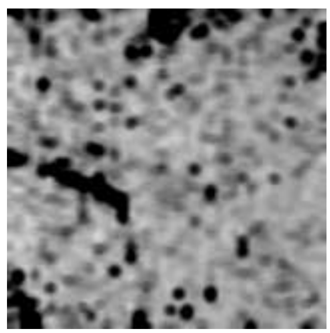
A. Interpretation of non-integrated geophysical datasets

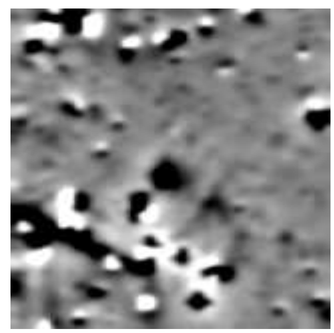
This part is to be done without *ArchaeoFusion.* The point is that you will have to examine each one separately without the advantage of overlay and integration offered in *ArchaeoFusion*. It is ok if the software you use allows you to overlay the surveys, but please don't spend much time comparing the data. The point is to look at them separately for this part.

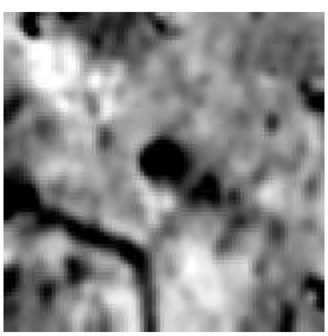
1. Download the five surveys (png images) OR use the versions pasted in this document (below). These surveys were processed in *ArchaeoFusion* and exported. Each is 20 x 20 m, with north up, and using a reverse gray colormap (black indicates positive anomalies). Here are the image files:
   ftp://ftp.cast.uark.edu/outgoing/eernenw/AF_eval/conductivity.png
   ftp://ftp.cast.uark.edu/outgoing/eernenw/AF_eval/GPR16-20ns.png
   ftp://ftp.cast.uark.edu/outgoing/eernenw/AF_eval/mag.png
   ftp://ftp.cast.uark.edu/outgoing/eernenw/AF_eval/MS.png
   ftp://ftp.cast.uark.edu/outgoing/eernenw/AF_eval/res.png

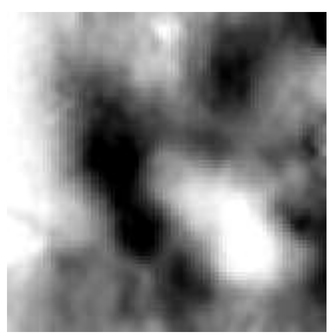
2. Here are the surveys if you would rather copy and paste.


Conductivity


GPR 16-20 ns


magnetometry


Magnetic Susceptibility


resistivity

3. For *each separate* data type (magnetometry, resistivity, conductivity, magnetic susceptibility, and one GPR slice (16-20 ns)) do the following:

a. Examine the image and identify ALL anomalies (even ones you don't think are cultural features) above noise level.
b. Using your software of choice (Surfer, Photoshop, ArcMap, PowerPoint, etc), vectorize (outline) or otherwise mark and number each one.
c. Examine each anomaly and judge whether it is a feature anomaly (an anomaly that you think is *likely* to be an archaeological feature) or not based on anomaly amplitude, contrast, size, shape, relative location, and any other characteristics you can discern. DO NOT, however, use other datasets as comparison (i.e. do not check to see if the anomaly shows up in other datasets. We will do that in the next part).
d. Paste the image of each dataset with the anomalies marked and numbered into a document.
e. Make a list to show which anomalies are interpreted to be feature anomalies and which are not. State the total number of anomalies, and the total number of feature and non-feature anomalies. You could use a table such as the one suggested in the deliverables section above.

B. Examination and comparison of anomalies in ArchaeoFusion.

1. Download the *ArchaeoFusion* project "LosAdaesProjectN610E470".
   ftp://ftp.cast.uark.edu/outgoing/eernenw/AF_eval/LosAdaesProjectN610E470.zip
   The project is a folder with several subfolders and files. When you unzip, do not accept the default to place the zipped contents into a new folder entitled LosAdaesProjectN610E470. When you unzip the files they will already be in a directory by this name and creating another parent directory will mean that you will have to go in a level deeper to open the project directory from *ArchaeoFusion*. It will work that way, but can get confusing.
2. Launch *ArchaeoFusion* and open the project.
   Go to File→Open Project, and then browse to the Project folder titled "LosAdaesProjectN610E470". DO NOT double click on the folder to select it. Simply select the project folder with one click and then click the select button. Leave the check box checked to "let this project reset the coordinate system preference" and click Finish.
3. Each of the five datasets is listed in the left column. For this exercise you will use the check boxes to turn the surveys (layers) on and off so you can see each one (surveys are on top of one another like in a GIS, and the survey listed at the top of the list is at the bottom of the pile in the viewing window, behind the others).
4. You may also want to adjust the contrast for individual surveys. To do so you can either drag the slider bars, or right-click on the triangles at each end and enter a value (in standard deviations), then press enter. To change the color display you can turn the red, green and blue bands on and off using the radio buttons, or, you can change the colormap using the drop-down menu located in the right panel of the software window. You can ignore the EM38 survey, since it has been broken apart into separate conductivity and MS surveys. We are only using one GPR slice (16-20 ns) for this part.
5. To pan around and zoom in and out, you can use a 3 button mouse, or the four buttons in the upper-right corner of the main viewing window. The main (left) mouse button shows you values for each pixel (see below). Use the wheel to zoom in and out (D=Dolly), and hold

down the wheel or center mouse button and drag to move the survey around (P=Pan). Right click to change the viewing angle (R = Rotate). After messing with the last one you can go back to a flat, north-up view by right-clicking on the survey name in the survey list (left) and selecting "go to survey."

6. You may also want to explore the values for a survey and survey coordinates. To do so, highlight the survey in the survey list (white in the list on the left) and place the mouse over that spot and hold down the mouse button (left click). The top line gives you the values for that location (multiple values if there are multiple bands, as with GPR and EM). The middle line gives you the survey coordinates. The bottom line gives real world coordinates, but for this case we are not using them so the lower-left corner is given the false coordinates of 0,0 latitude, longitude.
7. Now check each anomaly in each survey against the other surveys, and determine which anomalies are also found in other surveys. For each anomaly in each survey, report which other surveys it also occurs in, and then the total number of other surveys in which it occurs. A table such as that given in the deliverables section above would work well for this, and will make the evaluations much easier to compare and summarize.

Part II: Objectives 2-3. The case for Data Integration

Claim: Integration of multiple geophysical datasets improves potential for detecting archaeological features when compared to non-integrated data, and *ArchaeoFusion* makes this possible and efficient.

What you need:

- Same as above (LosAdaesProjectN610E470)

Deliverables:

1) Use *ArchaeoFusion* to integrate or fuse some of the Los Adaes datasets and save the results as images (you will learn to use PCA, the Band Calculator, and transparencies).
2) Answer two multiple choice questions about your experience.

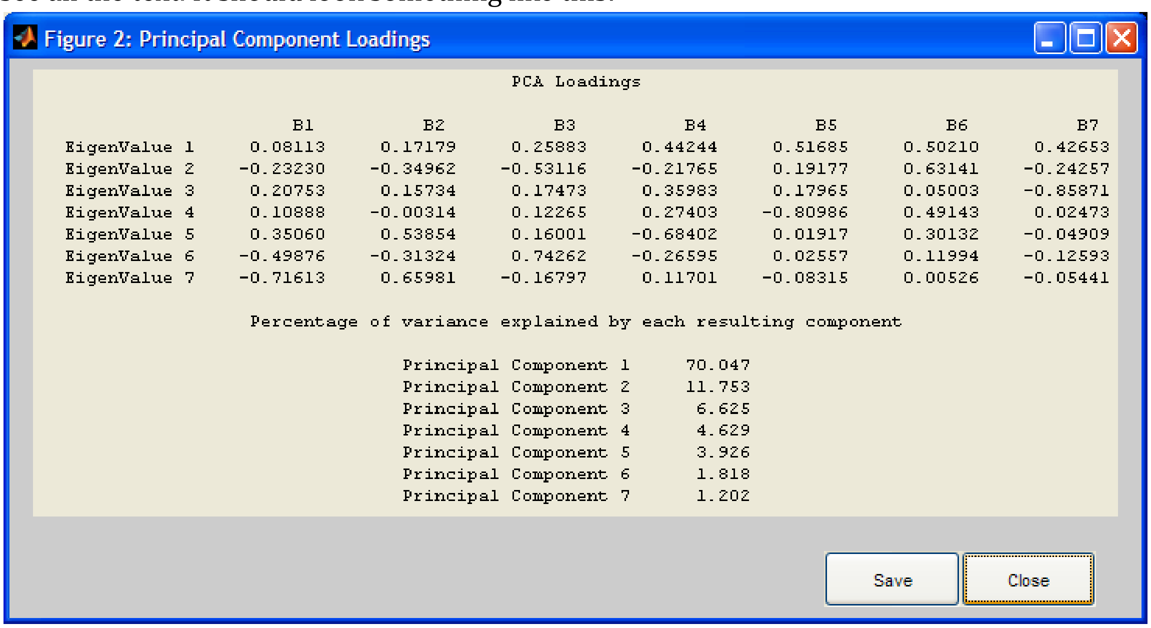
Instructions:

A. Principle Components Analysis (PCA) of GPR slices.

It is often the case that each GPR slice contains different parts of the same anomaly, but if slices are made too thick other anomalies are not visible. It is sometimes desirable to summarize all of the information from several slices into one image. In consolidating all the slices into one you lose depth information, but this can be determined by comparing the fused slice image to the originals and to reflection profiles as needed. PCA is a useful technique for fusing different types of data too, but it works best with highly correlated images (as is often the case with GPR slices).

Principle components analysis (PCA) is a mathematic procedure that transforms a number of correlated input images into output images ("components") that are uncorrelated. The first principal component usually accounts for most of the variability from all the input images, and each successive component summarizes less and less of the total variation. So if the input images are highly correlated (as is often the case with GPR slices), then the first principal component is often a very good summary of multiple slices. PCA also works well with different types of geophysical data.

1. Open the Project "LosAdaesProjectN610E470". NOTE: You should periodically save your project throughout this exercise to prevent losing work.
2. Select (highlight) the GPR survey in the Survey List (left panel) and uncheck all the others.
3. In the operation stack below (left panel, bottom), uncheck all of the operations.
4. Click "run operation stack". This will show you the original GPR slices. To look at each one separately, click the radio buttons next to the band numbers in the survey list. Notice that each slice contains similar information, but some of the anomalies are broken up into different slices. You can imagine that if added together they might be easier to interpret.
5. Add a PCA operation by clicking on the button in the operations toolbar, or by selecting it from the Operations menu in the menu bar.
6. Click "Run Operation Stack"
7. Before looking at the results, take a look at the numerical results in the new matlab window (it may be behind your window – look for it in the taskbar). Expand the window so you can see all the text. It should look something like this:



PCA Loadings

	B1	B2	B3	B4	B5	B6	B7
EigenValue 1	0.08113	0.17179	0.25883	0.44244	0.51685	0.50210	0.42653
EigenValue 2	-0.23230	-0.34962	-0.53116	-0.21765	0.19177	0.63141	-0.24257
EigenValue 3	0.20753	0.15734	0.17473	0.35983	0.17965	0.05003	-0.85871
EigenValue 4	0.10888	-0.00314	0.12265	0.27403	-0.80986	0.49143	0.02473
EigenValue 5	0.35060	0.53854	0.16001	-0.68402	0.01917	0.30132	-0.04909
EigenValue 6	-0.49876	-0.31324	0.74262	-0.26595	0.02557	0.11994	-0.12593
EigenValue 7	-0.71613	0.65981	-0.16797	0.11701	-0.08315	0.00526	-0.05441

Percentage of variance explained by each resulting component

Principal Component 1	70.047
Principal Component 2	11.753
Principal Component 3	6.625
Principal Component 4	4.629
Principal Component 5	3.926
Principal Component 6	1.818
Principal Component 7	1.202

8. Look at the bottom half of the window, where it says "Percentage of variance explained by each resulting component." Principal component 1 explains 70% of the variance. This is good news and means that this may be the only slice needed to summarize all 7 of the originals. The remaining components may contain mostly noise and error, which is often more random.

9. Close the PCA Loadings window (you can save if you want, but it is not necessary)
10. Now look at the GPR survey. The bands (B1-B7) are now showing the principal components. Clearly the first one shows the main anomalies so we will save this to a new file and process it for interpretation later (note that you can do PCA on processed data, but I like to do it on the raw data because it is a good technique for noise reduction and so you can then process the result for a better final result).
11. Click Tools→ Merge/Break Up Surveys. In the dialogue, check the box next to "Keep base layer resolution." Enter a new Survey name: GPR PCA C1 (for GPR PCA Component 1). In the list of bands at the left, click on GPR B1. It will jump to the box at the right. This band will become Band 1 of the new survey. You could save the other components here as well, but we only need the first component. Click Finished. The new Survey is inserted at the bottom of the survey list.
12. We can process this new survey using the same operations that worked well for the GPR slices. To do so, go back to the GPR survey (click on it in the list to highlight white). Make sure the new GPR PCA C1 survey is unchecked. Delete the PCA operation, check all the other operations, and click "run operation stack." Next, click Operations→Save Operations… and save the operation stack. Give it a name, such as "GPRoperations" and save.
13. Now we will load the GPR operations to the GPR PCA C1 survey. Highlight the GPR PCA C1 Survey and check the box so it is displayed. Go to Operations→Load Operations… and browse to the "GPRoperations" file that you just created. Click open. The entire operations stack is now added to the survey.
14. You can run all of the operations at once, or one operation at a time. Let's do one at a time so you can see what is being done.
15. Check Resample, expand the operation (click the bar where it says "resample") to see the input parameters, and run the operation stack. Resample changes the data density of a survey (you can increase or decrease the number of pixels). This is an important first step with GPR data because the original data contains hundreds of readings in the profile direction, but a reading every half meter in the other direction.
16. Check Destagger, expand it, and run the operation stack. Destagger shifts every other row (or row pairs for special circumstances) to compensate for timing errors during data collection.
17. Check ZMT, expand it, and run the operation stack. ZMT (Zero Mean Traverse) equalizes the mean, median, or mode of traverses. Often the median works best.
18. Check Standardize, expand it, and run the operation stack. Standardize rescales the data on a scale of -1 to 1. Outliers are permitted, which is why the new standardized scale goes up past 20. This is not necessary since the PCA results are already standardized, but it was already in the operation stack and won't harm anything. You can delete it if you like using the X to the right of the operation.
19. Check Clip, expand it, and run the operation stack. This operation clips the data within the specified range, in this case -2 to 2, improving contrast.
20. Check Resample, expand it, and run the operation stack. This is done a second time now that the data are processed, in preparation for smoothing. You see no change because the

resolution in the x direction has only been doubled, and a nearest neighbor operation is used to duplicate pixels.

21. Check Spatial Filter, expand it, and run the operation stack. Spatial Filter gives you the option of running high or low pass filters on the data. The disk filter does a nice job of smoothing out the data.
22. Now you can save the result to an image file for one of your deliverables. Here are the instructions:
    a. In the survey list on the left, highlight the survey you want to export (it will be highlighted white after you click on it). Make sure you are happy with the way the image looks (contrast and colormap look ok, etc.).
    b. Tools → Export Survey
    c. Enter a file name
    d. Choose by image size or pixel size. I suggest exporting by pixel size and entering 0.125 x 0.125.
    e. Choose WYSIWYG (What You See Is What You Get) so that the exported image appears as it does on the screen.
    f. Image Format: PNG is best for this situation, since we don't care about geographic coordinates. It can be opened by almost any program, and even goes directly into ArcMap.
    g. Click Finish. Image will show up in the main Project directory "LosAdaesProjectN610E470"

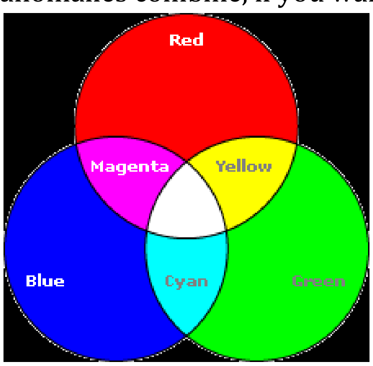
B. Translucent Overlays.

ArchaeoFusion has several options for viewing multiple datasets on top of one another as translucencies. This allows you to see several layers at once, up to a limit of course (at some point you simply can't see through too many layers).

Instructions:

1. Open the same project (LosAdaesProjectN610E470) if it is not already open.
2. Look at all the surveys and to decide which ones you want to overlay. Let's try MS and mag first, to see how they compare to one another.
3. Using the small arrows to the right of the check boxes, move the mag and MS surveys to the top of the survey list so they are easily found and next to each other. Put the MS survey at the very top, with mag directly below it.
4. Now change the colormap (right panel, near the top) to regular grayscale (grades from black to white, so positive anomalies are white)
5. Check the box to display the MS survey (uncheck all other surveys), and use the radio buttons to make it appear red. Notice that the positive anomalies are now bright red.
6. Now check the mag survey so it appears on top in the viewing window. Select only the green radio button. The positive anomalies are now green.

7. With both surveys checked (displayed), click on the plus signs to the left of the survey names. This makes each one transparent and blend with any other survey that are also transparent (also have the plus sign changed to a minus).
8. Now you can see that the anomalies in these two surveys are similar, but slightly offset! Positive MS anomalies are red, and positive mag anomalies are green, and where they overlap appears yellow. Why are they offset? This is not the subject of this software evaluation, but an interesting finding nonetheless. My hypothesis is this: I think the mag data are spot on, but the MS data (and conductivity, because both are collected with the EM38B) are about one meter too far north. This can easily be explained by positional error with the EM38, which happens to be 1 meter long (will have to check the data source to find out for sure).
9. Now let's add one more dataset: GPR PCA C1. Find this survey and move it up so it is directly under the mag survey in the survey list. Check the display box so we can see it (you have to uncheck the other two surveys also). Change its color to blue and notice that the positive anomalies, including what looks like the palisade anomaly, are now blue.
10. Click the plus sign to make this survey transparent, and then check the MS and mag surveys so you can see all three at once.
11. You can tell the anomalies from different sources apart by the colors, and you can also figure out which anomalies overlap by the color. According to the RGB color model, magenta means blue (GPR) and red (MS) are overlapping, yellow means red (MS) and green (mag) are overlapping, and…you get the idea (see color model below). If all three overlap you get white. You could do the same thing using the reverse gray colormap to see how the negative anomalies combine, if you wanted.



12. Again we have anomalies that do not line up. The GPR anomaly for the palisade is way off. I think it is actually showing the location of the reconstructed palisade, which was removed prior to the survey, but which left marks on the surface. I will have to check the profiles, however, because the slices show that the palisade anomaly shows in the deeper slices only. Could be multiples that got magnified with depth by gaining the signal. But I digress…
13. So, this is a quick and easy way to view multiple datasets. Since it is for display only and involves multiple surveys, it cannot be exported as one image. You should save the project, and print screen to paste into your report. We will actually recreate this using bands in a single survey in the next part so you can export it as an image. This is just a fast and easy way to use these tools to help interpret the data.

C. Mathematical Fusion Using the Band Calculator.

The Band Calculator is a tool that works as an operation in the operation stack. Using this tool, you can perform most mathematical operations on multiple bands of data. For this evaluation we will put several of our surveys into one survey (as separate bands) and then combine them by adding them together. You can also experiment with the max function (enter B6 = max(B1,B2,B3,B4,B5)), and using the reclassify operation to create binary or ranked images and then adding them together. But there is not enough time to do this here.

Instructions

1. Open the same project (LosAdaesProjectN610E470) if it is not already open. Change the minus signs back to plusses from the previous section, and uncheck these surveys so they are not displayed. If you have continued working from the previous part, make sure to save the project.
2. Now that we know that the EM (MS and Conductivity) data need to be shifted south, we can correct this problem before combining all the datasets. Here is what to do:
    a. Find the MS Survey and make sure it is highlighted white in the survey list
    b. Click the “Edit Survey” button on the shortcut bar (it is located directly under the Operations menu), or you can go to File→ Edit Survey.
    c. This opens the Survey Tool, where we will nudge the survey south.
    d. Find the snap size box along the top, toward the right. Change it to 1 and you will see the grid lines change so they are now spaced 1 unit (meter in this case) apart.
    e. Normally you would have to select the tile you want to move, but in this case it is already selected since it is the only tile in the survey.
    f. Now you can use the arrow keys located at the bottom right to nudge the tile once to the south (down). It will move according to the snap size. Alternatively, you can move it with the mouse, but nudging is easier for small distances.
    g. Click finished. You will have to rerun the operation stack on the “new” survey, so click “Run Operation Stack” and be patient while it reruns all the operations.
    h. Now you can display the MS as red and the mag as green and click the plus signs to see how they line up (remember to change the colormap to regular grayscale, black to white) (you don’t need to display the GPR for this). Much better! Where the two line up is yellow! Would probably work even better if the mag data were not dipolar!
3. Now do the same exact thing for the conductivity survey.
4. Create a new survey with each processed geophysical survey as one band:
    a. Click Tools→Merge/Break Up Surveys
    b. Uncheck the box next to “keep base layer resolution.”
    c. Select “Set Pixel Size”
    d. Enter .125 x .125 meters for the new x and y pixel sizes
    e. Enter a new survey name: Math Fusion

f. Select the following bands from the left column, in this order: Conductivity B1, res B1, mag B1, MS B1, GPR PCA C1 B1 (we will use the fused GPR for this).
g. Click Finished

5. Now we will label the new bands so we don't forget which one is which. Highlight the new survey in the survey list, right-click on it, and choose Edit Band Labels. Enter the names of each of the input surveys for B1-B5: Cond, res, mag, MS, GPR C1. (I KNOW – this should be done automatically – working on it..)
6. Now we can recreate the red-green-blue (RGB) overlay and save it as an image, but it will be better now that we have fixed the MS survey. Simply use the radio buttons to make the mag green, MS red, and GPR blue, and change the colormap to regular grayscale – black to white. The result should look identical to what we created using the translucent buttons (plus-minus signs), except now the MS and Mag anomalies line up better.
7. Save this as an image (name it RGB_ms-mag-gpr or something to that effect) for one of your deliverables. Here are the instructions again:
    h. In the survey list on the left, highlight the survey you want to export (it will be highlighted white after you click on it). Make sure you are happy with the way the image looks (contrast and colormap look ok, etc.).
    i. Tools → Export Survey
    j. Enter a file name
    k. Choose by image size or pixel size. I suggest exporting by pixel size and entering 0.125 x 0.125.
    l. Choose WYSIWYG (What You See Is What You Get) so that the exported image appears as it does on the screen.
    m. Image Format: PNG is best for this situation, since we don't care about geographic coordinates. It can be opened by almost any program, and even goes directly into ArcMap.
    n. Click Finish. Image will show up in the main Project directory "LosAdaesProjectN610E470"
8. Now we are ready to use the band calculator. First, you will add a blank band so you have a place to save the new result. Click Tools→ add a band. A blank band is added to the bottom of the survey band list.
9. Next, we need to get all the different data types on the same scale. To do this, add the Standardize Operation (from the Operations menu or the shortcut button along the top), and accept the default "by survey" mode, and click "Run Operation Stack". Here is a little info about this (skip if you are in a hurry): Before this operation the data were in their native units (nanotesla, ohms, etc.) and had very different ranges (you can check the histogram in the lower part of the right panel (click the standardize operation in the stack to open it, which show the data before that operation is run, if you want to compare the histograms before and after). The top histogram is for the whole survey, and you can scroll through the five datasets (bands) using the arrow keys. The min and max values are given below each histogram, and the mean and standard deviation below that. Standardize simply transforms the histogram so that the mean is zero and the standard deviation is 1, to make data more comparable. If you select "by survey" then it treats the entire survey (usually

made up of multiple tiles or "grids") as one for the standardization. If you choose "by tile" then each tile is standardized (kind of like "zero mean grid" in Geoplot, if you are familiar, except the standardize operation also equalizes the standard deviations).

10. Add a Calculator Operation by clicking the button in the shortcut menu bar along the top, or choosing it from the Operations menu. Write a function to add all of the bands together
    a. Leave the radio button selection to "all"
    b. For the left side of "=", select B6 (this is the blank band, where the result will be written)
    c. For the right side of "=" enter "B1+B2+B3+B4+B5" (you can type it in, or use the band buttons and plus button.
    d. Run the Operation Stack
    e. The result (Band 6) nicely shows most of the major anomalies from all the data. There are still a few problems with it though. Mainly, the magnetometry data have dipolar anomalies, and these mess up the math. This is why there is a gap in the palisade anomaly near the south edge of the survey area. You can look at the mag data and see why. Also, the conductivity and res data are basically the inverse of each other, and so they are mostly cancelling each other out. You could fix these problems by taking the absolute value of the magnetometry data, and by inverting the res data (both could be done with the band calculator), but for now we will keep this simple and stop here.
    f. To simplify the result, let's just omit the conductivity and res data. Click on the calculator bar in the operation stack to open the operation. Now delete the B1+B2 part of the expression so that it reads B6 = B3+B4+B5. Run the operation stack again.
    g. Right click on the Math Fusion Survey in the Survey List and click Edit Band Labels. Name Band 6 "Sum3-5"
11. Save the project and then save the "Sum3-5" band as an image (follow instructions given in step 7 above).

D. Multiple Choice Questions

Please answer the following two multiple choice questions with reference to your experience from the exercises above (PCA of GPR slices, translucent overlays, and mathematical sum).

1) Integrating multiple datasets using *ArchaeoMapper* increased my ability to detect feature anomalies.

a Very true
b Somewhat true
c Neither true nor false
d Somewhat false
e Very false

2) Integrating multiple datasets using *ArchaeoMapper* increased my ability to determine one or more characteristics of the feature anomalies (e.g., feature size, shape, depth, relative location to other anomalies, whether it was burned, presence of rock concentrations, etc.).

a Very true
b Somewhat true
c Neither true nor false
d Somewhat false
e Very false

Part III: Objectives 5 & 7: The case for *ArchaeoFusion*

Claim: (A) Data from the main types of geophysical sensors (magnetometry, resistivity, GPR, and EM) can be adequately processed and integrated using only *ArchaeoFusion* (no other software is needed); (B) these results can be achieved more quickly with *ArchaeoFusion* than with other commercially available software packages; (C) *ArchaeoFusion* records metadata more accurately and completely than comparable software.

What you need:

- Original data files for four adjacent tiles ("grids") of data from four different types of instruments from Los Adaes.
  - GPR: GSSI SIR-3000
  - EM: EM38B & EM38MK2
  - Magnetometry: Bartington Grad601-2
  - Resistivity: Geoscan RM-15
- Instructions and guidelines given below.

Deliverables (it will help to read through all of these to see where it is going and plan how you will do things):

1) Time required to process and integrate at least two of the Los Adaes datasets in your software of choice (whatever you normally use, not *ArchaeoFusion*). If you have experience with GPR and/or EM then we need you to choose these since this is the biggest strength of *ArchaeoFusion*. If you are only familiar with one method then that is ok, but try to use a second if you can. It would be best to get a detailed time log from you for each step of the way – e. g. how long it took to import and assemble the EM data, then to process it, then to preprocess the GPR data, slice it, assemble slices, process them, then integrate both together. If you do not know how to integrate multiple datasets then just state that this part could not be completed given your experience or limits to software.
2) Instructions for another person to replicate what you did. Think of this as creating an archive, which should contain raw data, finished results and a description of how the results were achieved. It is up to you how you want to do this. You might decide that you want to avoid being software-specific, or you could provide directions requiring a certain software. This is one of the challenges of creating a data archive. This can also be time consuming and

so you should be realistic about how much detail you are able to provide given your time constraints. It could range from a copy of hand-written notes to a more formally written document. If your archive does not contain all of the details required for someone else to reproduce what you did then this is simply a reality and helps identify where geophysics software needs improvement.

3) Time required for you to replicate another person's results by following their directions (please complete the other deliverables and you will be notified when there are instructions from someone else for this part.)
4) Time required for you to process and integrate the provided Los Adaes datasets using *ArchaeoFusion*. Again, try to provide a detailed time log like the one for your work in other software. Step-by-step instructions for this are provided below.
5) Instructions for another person to replicate what you did using *ArchaeoFusion*. Just as for #2 above, think of this as an archive with raw data, final results, and a description of how the results were achieved. This could look something like what is provided for you in the instructions below. *ArchaeoFusion* will eventually have an export function for creating an archive (will include raw data, results, and all processing steps), but it will not be ready for the first version. In the mean time, you can get data processing information for each survey by opening the "survey.operationlist" file in WordPad. This file is located in the project folder under surveys, and then the name of the survey. For example, for the res data used in the first project the file is here: LosAdaesProjectN610E470\Surveys\res\survey.operationlist. You can also save the operation stack and include it in the archive.
6) Time required for you to replicate another person's results by following their directions and using *ArchaeoFusion* (again, you will be notified when directions are ready for you. First complete the other deliverables and submit them, so your instructions can be used by another participant).

   *deliverables 3 and 6 cannot be done until we get deliverables 2 and 5 from other participants and send to you. Please complete 1, 2, 4, and 5 and send to us as soon as you can so we can send them to other participants to complete 3 and 6.

Instructions:

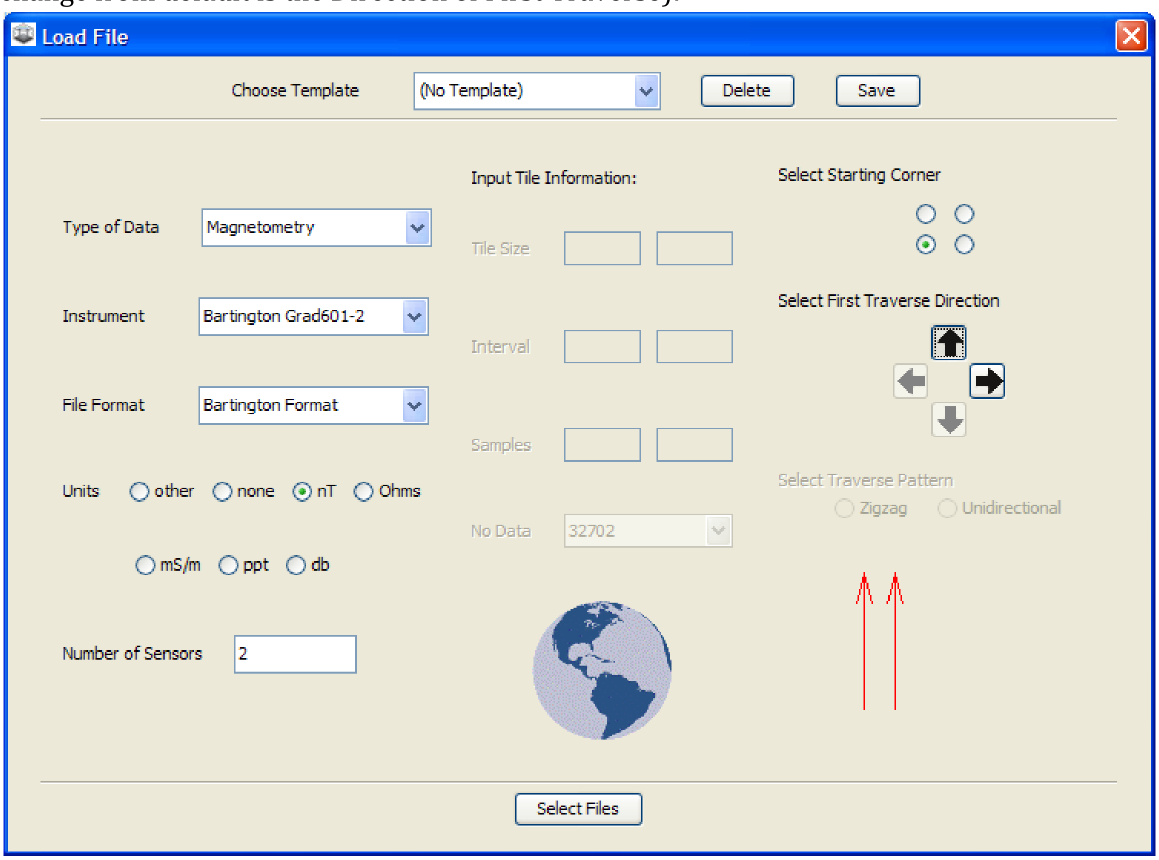
In this exercise we are testing the capability of *ArchaeoFusion* compared to other software. Since you are new to *ArchaeoFusion* and the user's manual is not yet complete, the instructions below will walk you through some of the steps required, but in other parts the guidelines are more general and you will have to make some decisions about the parameters for processing based on your own expertise. You only need to process the types of data that you are familiar with, although you can do the others if you wish. *PLEASE EMAIL EILEEN AS SOON AS YOU HAVE DECIDED WHICH DATASETS YOU PLAN TO USE FOR THIS PART.*

A. Creating a New Project .

1. Download and unzip the data from the following links (save in a directory that you will remember):
   ftp://ftp.cast.uark.edu/outgoing/eernenw/AF_eval/EM.zip
   ftp://ftp.cast.uark.edu/outgoing/eernenw/AF_eval/mag.zip
   ftp://ftp.cast.uark.edu/outgoing/eernenw/AF_eval/res.zip
   ftp://ftp.cast.uark.edu/outgoing/eernenw/AF_eval/GPR.zip
2. Launch *ArchaeoFusion* and select File→New Project
3. Name the Project "LosAdaesProject"
4. Browse to a location on your computer to save it. This could be the same place where you are storing the data. When you are in the chosen directory, click Select.
5. Click Finish

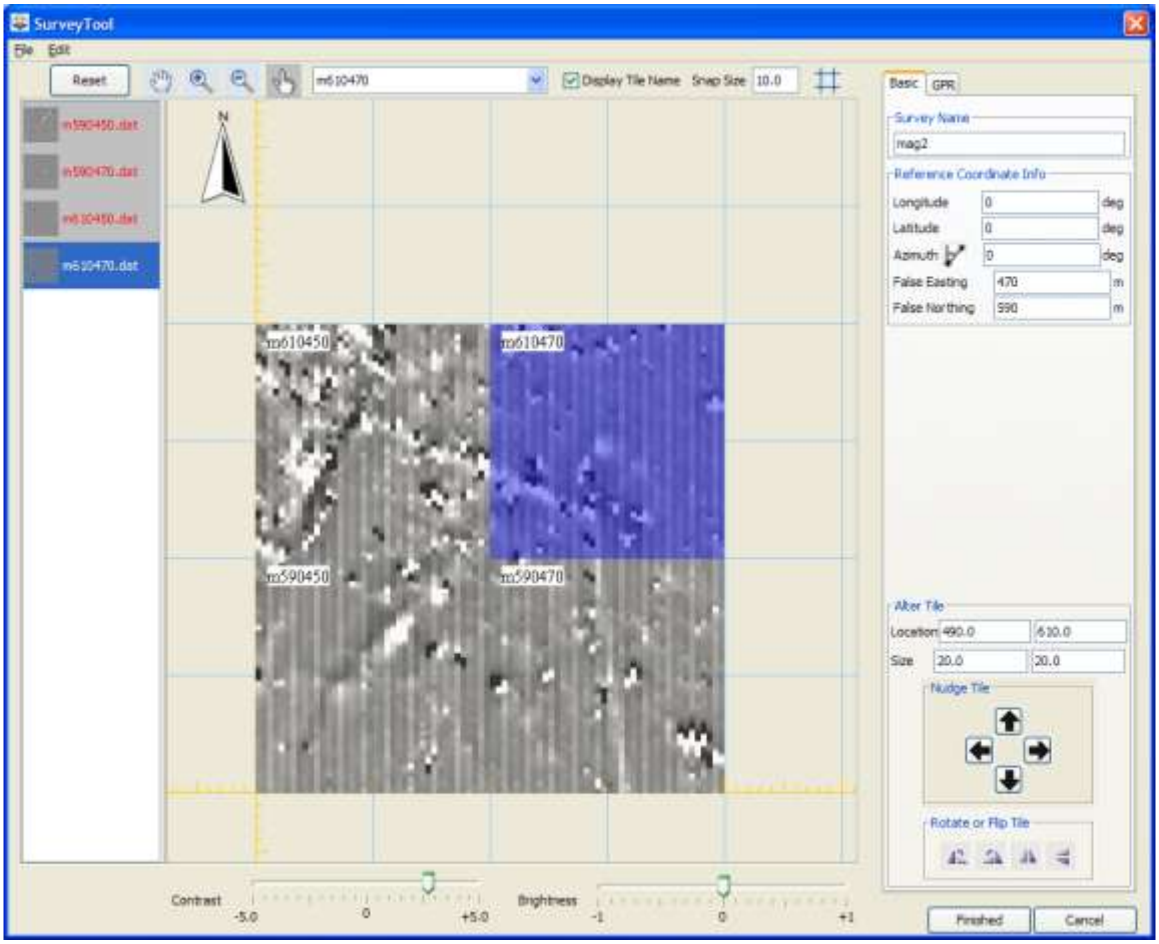
B. Loading Magnetometry Data

1. File→New Survey. This opens the Survey Tool
2. In the Survey Tool, Select File→ Add Tiles. This brings up the Load File dialogue
3. Select the following parameters for the magnetometry data (the only thing you have to change from default is the Direction of First Traverse):



4. Click Select Files

5. Browse to the data files and select all the magnetometry files (all have “m” prefix). Click Select Tiles
6. The tile names give the northing, followed by the easting. So you can arrange the tiles in the correct location using these coordinates. They should be arranged as follows:

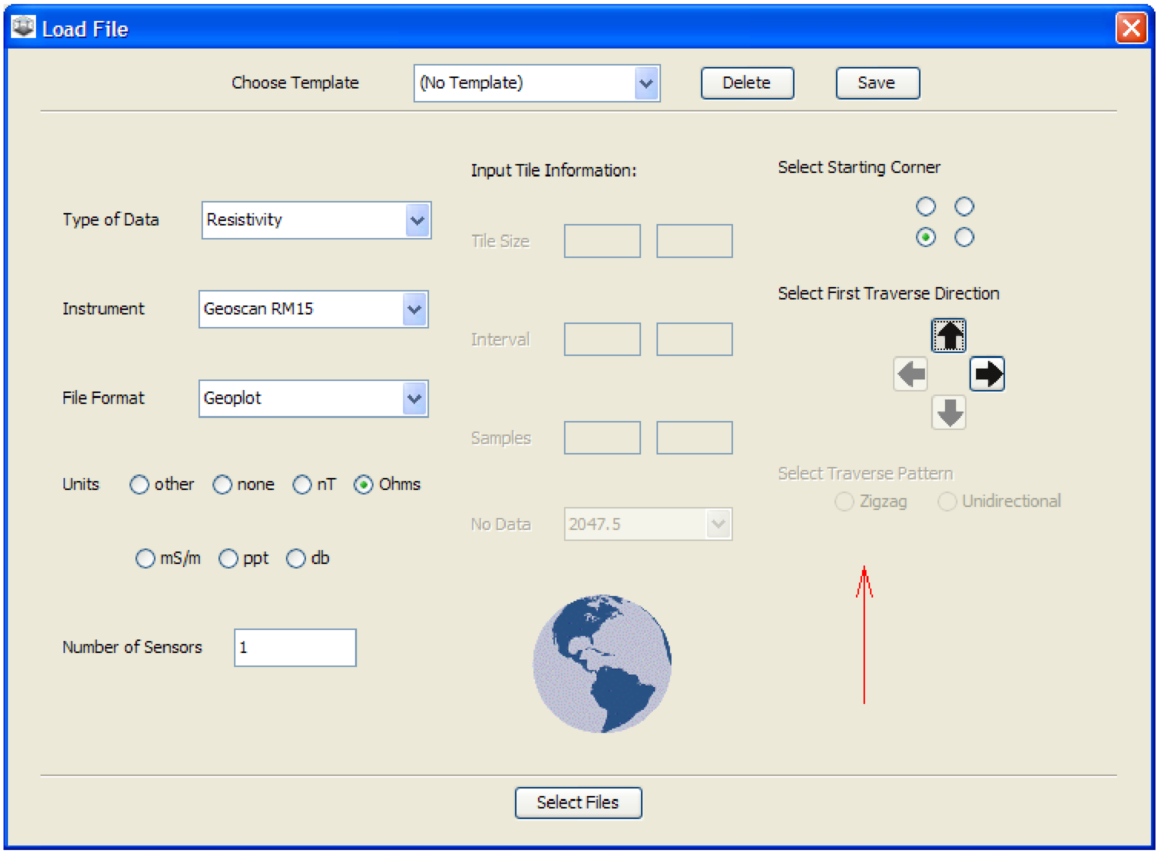


7. Enter the name “mag2” in the “Survey Name” Field in the upper right. At this point you could enter real world coordinates such as UTM but for simplicity we will just enter 0, 0, 0 for the longitude, Latitude, and azimuth. Even though it says degrees it will not treat the data as such unless we enter actual coordinates. Since we are working in plane coordinates, we can enter a false easting and northing, which corresponds to the intersection of the orange lines in the gridding window. Enter False Easting 450, False Northing 590.
8. Click Finished.
9. Click File→Save Project

C. Loading the Resistivity Data

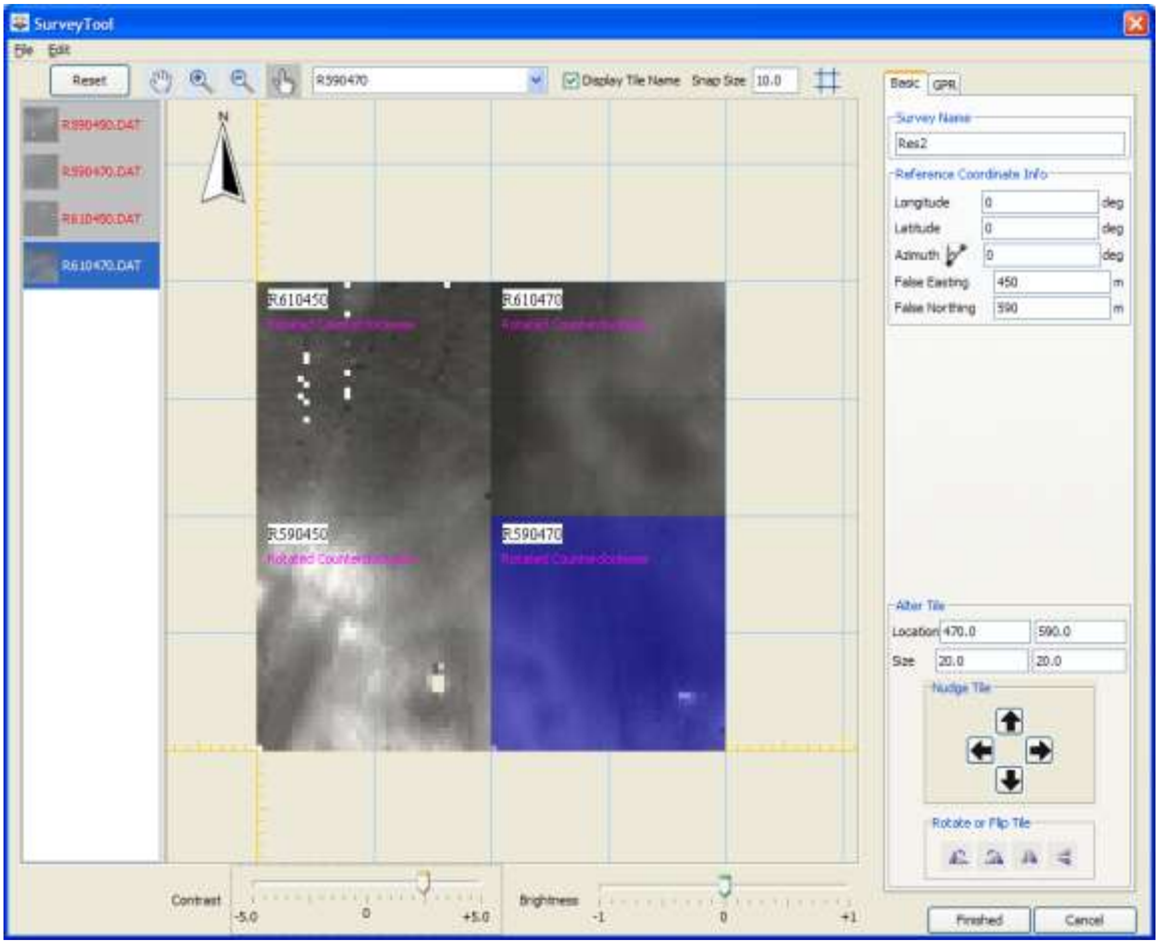
1. File→New Survey. This opens the Survey Tool
2. In the Survey Tool, Select File→ Add Tiles. This brings up the Load File dialogue

3. Select the following parameters for the resistivity data:



4. Click Select Files
5. Browse to the data files and select all the resistivity files (all have "R" prefix). Click Select Tiles
6. The tile names give the 3-digit northing, followed by the easting. So you can arrange the tiles in the correct location using these coordinates. This is a glitch right now with this import parser, so if the tiles come in incorrectly rotated, use the rotate tool (lower right) to rotate each one counterclockwise once. You can easily tell that they line up much better

after you rotate them. They should appear as follows:

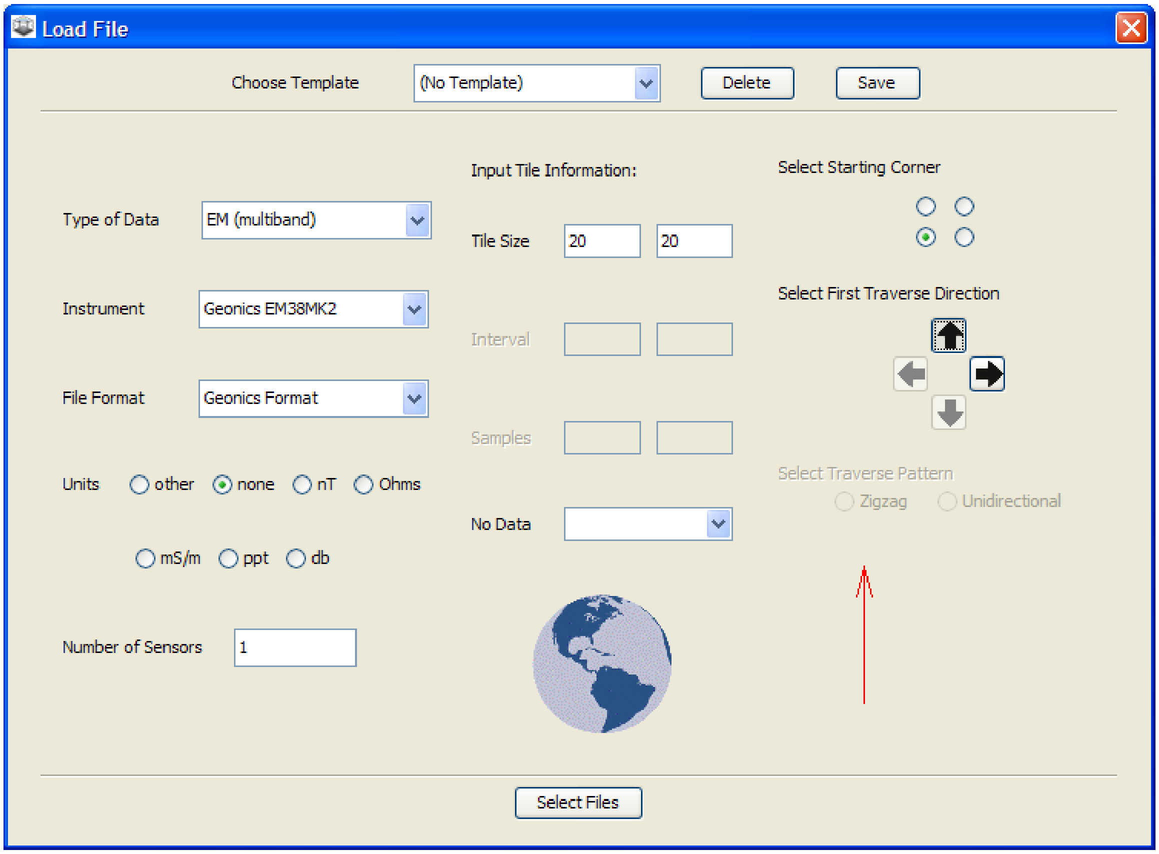


7. Enter the name “res2” in the “Survey Name” Field in the upper right. Enter 0, 0, 0 for the longitude, Latitude, and azimuth. Enter False Easting 450, False Northing 590.
8. Click Finished.
9. Click File→Save Project.

D. Loading the EM Data

1. File→New Survey.
2. In the Survey Tool, Select File→ Add Tiles. This brings up the Load File dialogue

3. Select the following parameters for the EM38MK2 data:

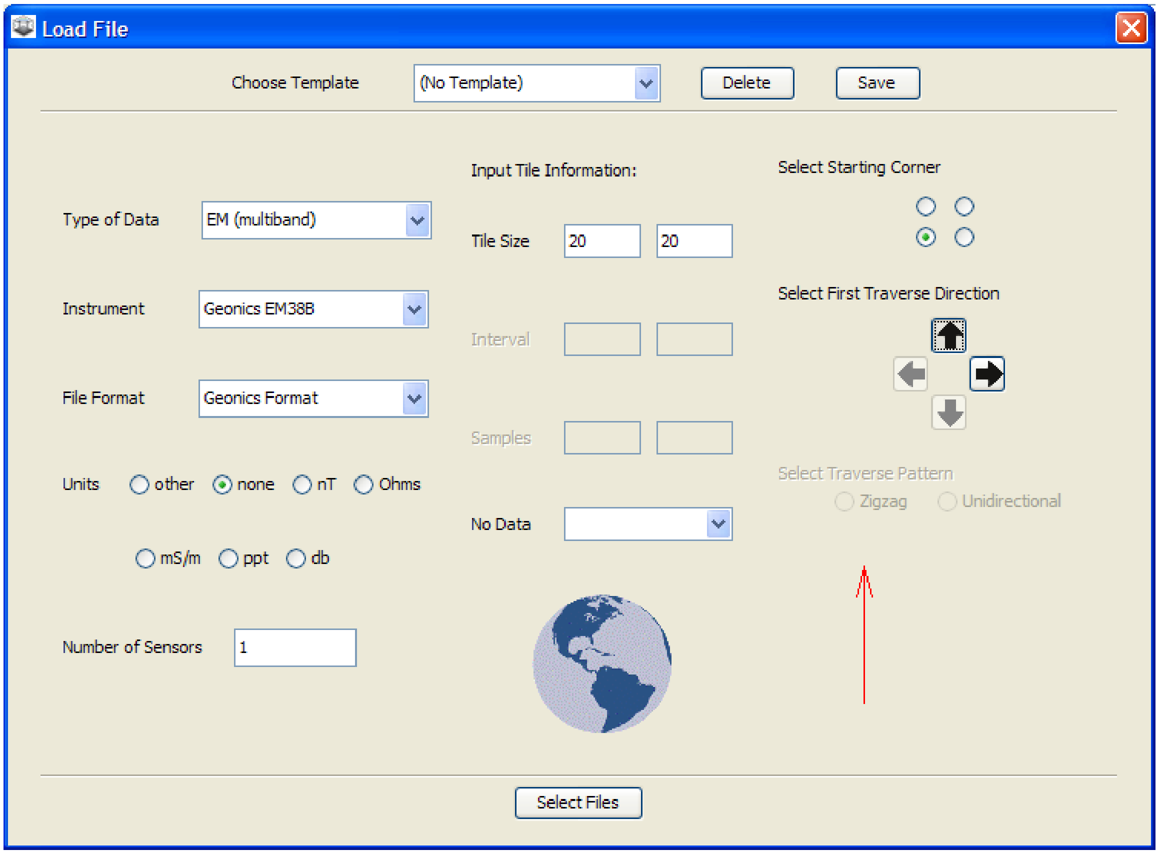


4. Browse to the data files and select the EM38MK2 file (there is only one: n590e450.N38). Click Select Tiles
5. This takes you to a window where you can edit the lines and individual readings if necessary.
6. Each of these lines should have 100 readings (numbered 0-99), so extra readings at the end of each line need to be deleted. Expand the window or scroll over to the right. You can delete whole columns (up-down lines) by clicking on the column heading. In this case, you can click on 111.0, 110.0, 109.0, etc and they will be deleted. Delete all the columns beyond 99. There will be a few rows with missing readings at the end.
7. Next, you will delete the extra rows at the top. Delete rows 40 and 41 by clicking on those numbers on either side of the row (rows go left to right). When you are done it should look

like this:

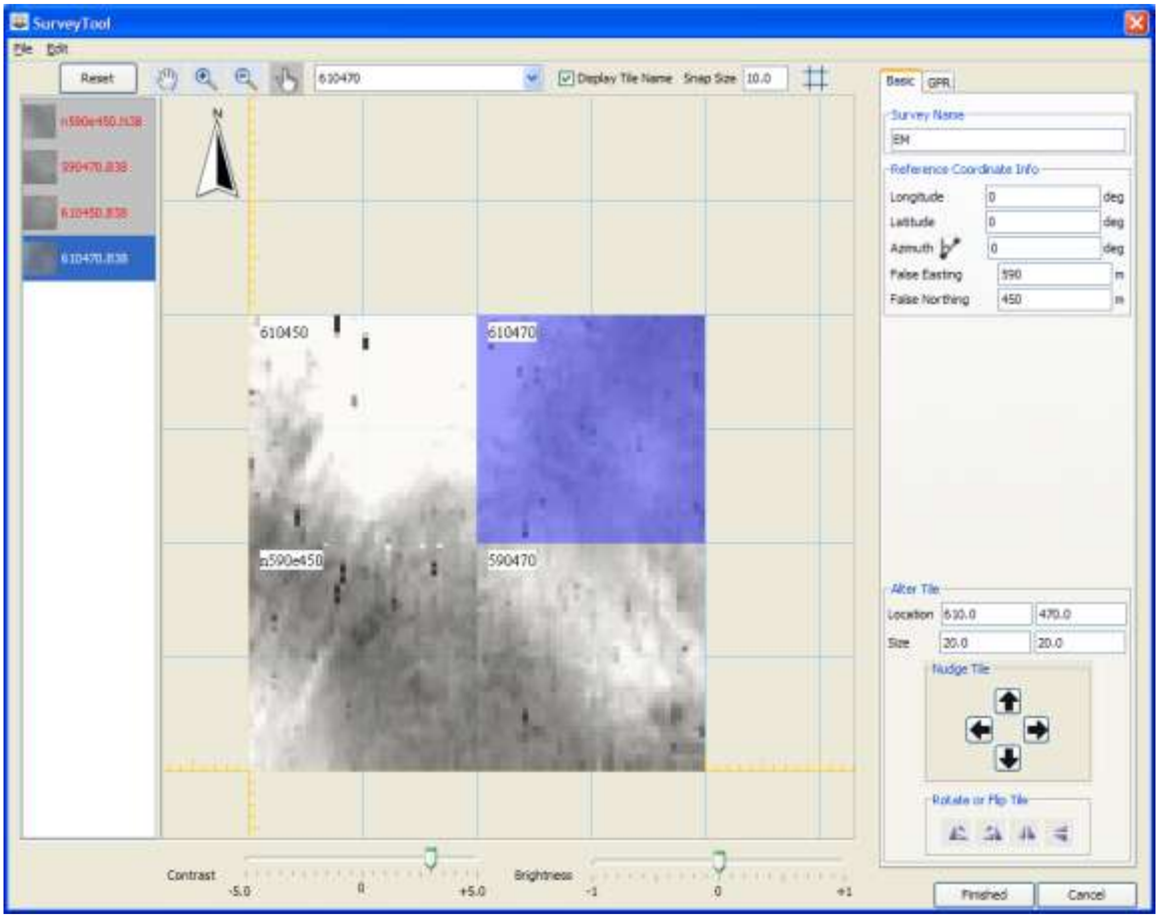
8. Click Finished.
9. Back in the Survey Tool, drag the tile into the gridding window and place it in the lower left corner.
10. Now we will load the other 3 EM tiles, which were collected with the EM38. Click File→Add Tiles

11. Enter the following parameters in the Load File Dialogue:



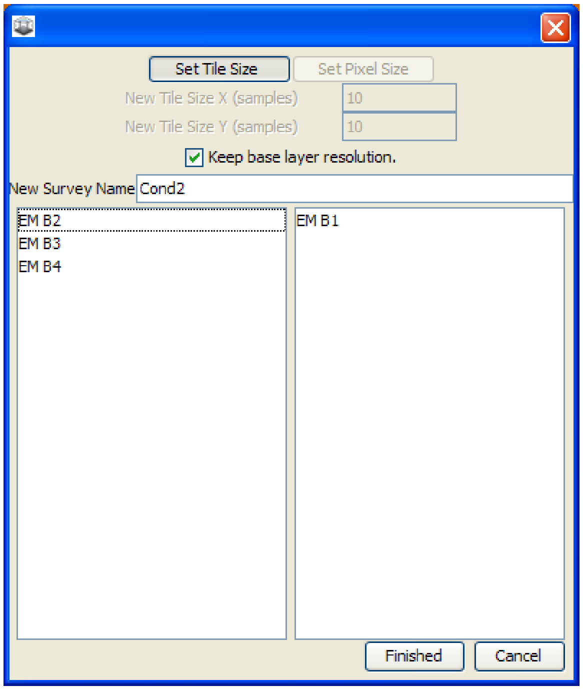
12. Click Select Files
13. Select the three EM38B files (the 3 files with the .B38 extension).
14. Each of these tiles will open in the EM editing window, just like the EM38MK2 file did. All of the files are fine as they are (each has 40 columns and 40 rows) so for each one you can just click Finished.
15. Drag these tiles to the gridding window and arrange according to the coordinates given in the file names. The file names give three digits for the northing and three digits for the easting. So file 590470 is at north 590, east 470.
16. Enter the name “EM2” in the “Survey Name” Field in the upper right. Enter 0, 0, 0 for the longitude, Latitude, and azimuth. Enter False Easting = 450, False Northing = 590.

17. The arrangement should look like this:

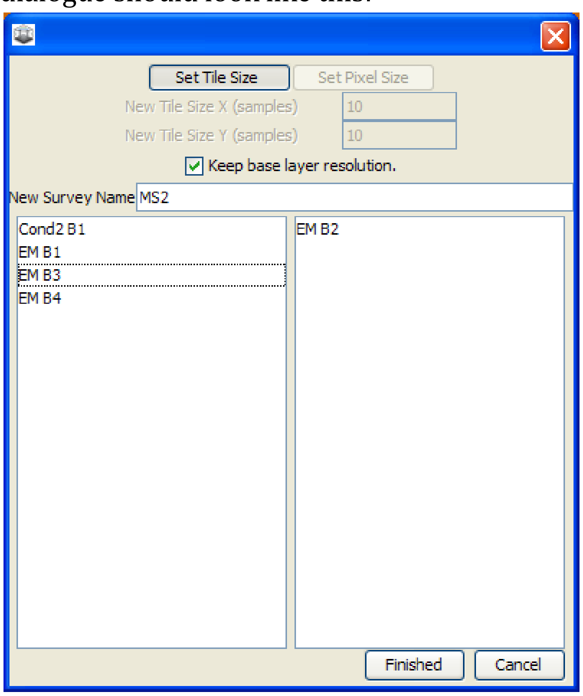


18. Click Finished. This will take you back to the main *ArchaeoFusion* window
19. Click File→Save Project to save the work you have done so far.
20. The new EM Survey is shown in the Survey List. Click on it so that it is selected. This survey has four bands because the EM38MK2 tile in the lower-left corner has four different data sets, in the following order:
    a. Band 1 = conductivity for the 1 m coil spacing
    b. Band 2 = magnetic susceptibility for the 1 m coil spacing
    c. Band 3 = conductivity for the 0.5 m coil spacing
    d. Band 4 = magnetic susceptibility for the 1 m coil spacing
21. If you click on the radio buttons to display the different bands, you will notice that bands 3 and 4 are blank for the three EM38B tiles. This is because the EM38B only collects data for the 1 m coil spacing. For this exercise we will only use the 1 m data. We will also create separate surveys for the MS and conductivity data, since they are so different and require different processing.
22. Go to Tools →Merge/Break Up Surveys

23. Create a Conductivity survey named Cond2 by entering the following parameters:



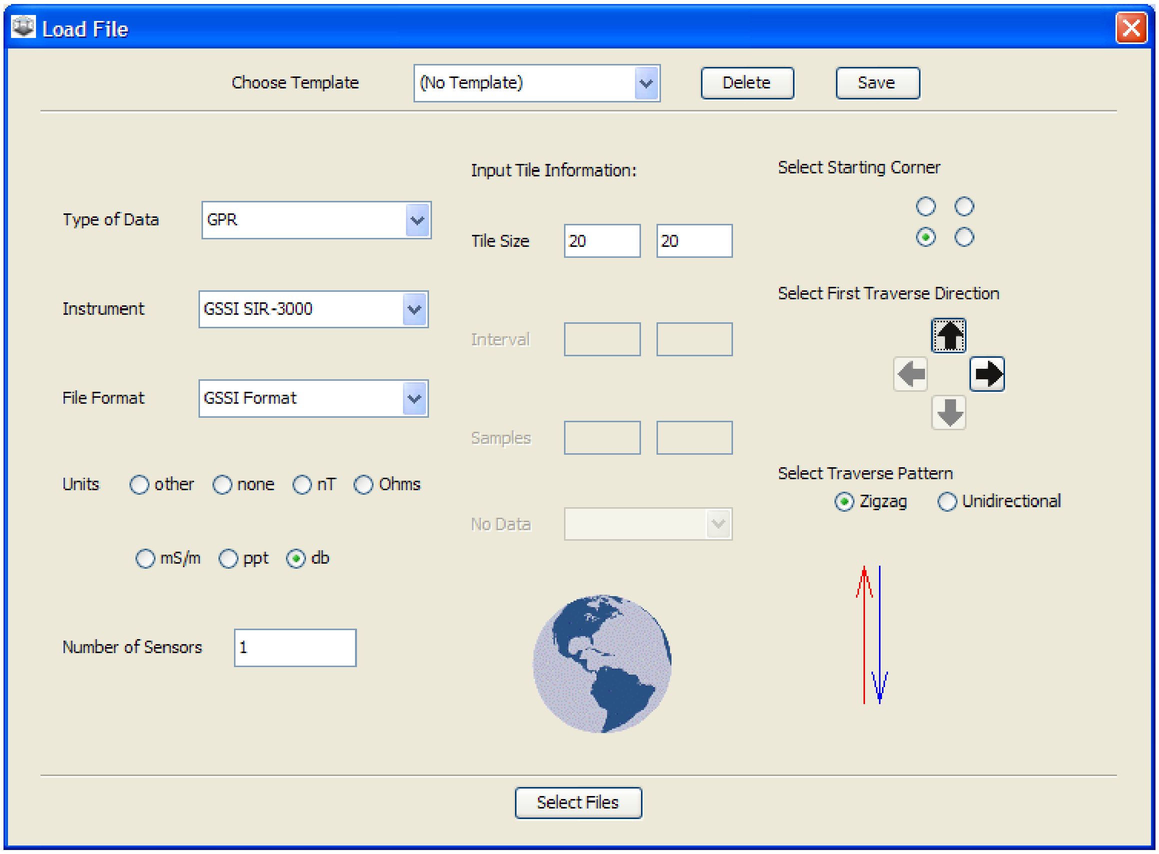
24. Click Finished
25. Follow the same procedure to create MS2 (for magnetic susceptibility) from EM B2. The dialogue should look like this:



26. Click Finished.
27. Click File→Save Project.

E. Loading and Slicing the GPR Data.

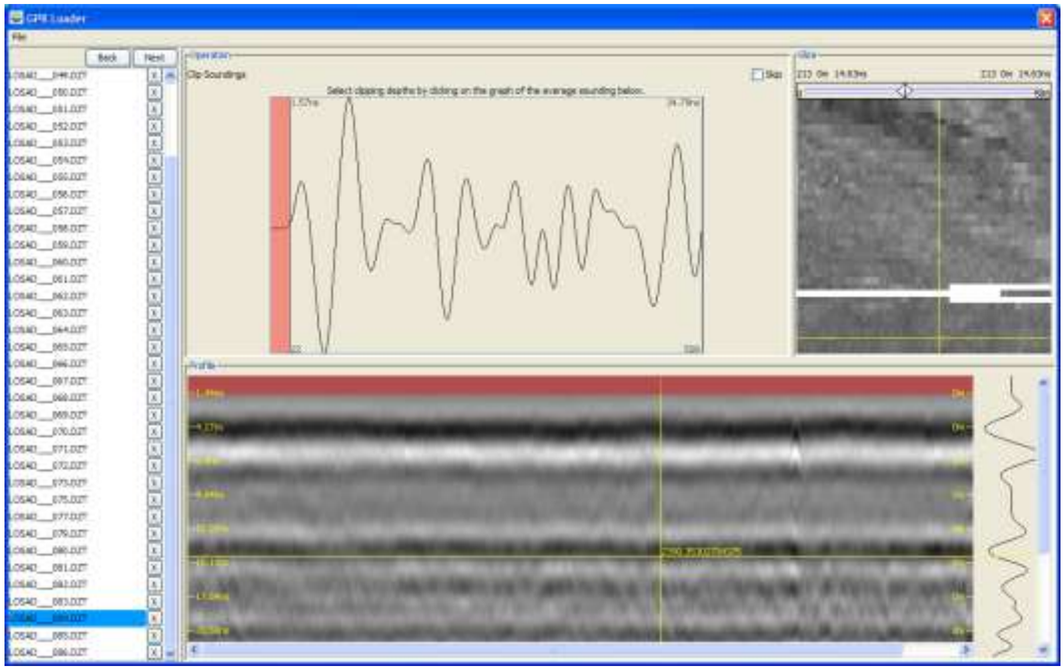
1. We will do only the minimum necessary for GPR profile processing here, for the sake of time. The GPR Loader is set up so that in many cases you can simply click next and default setting work, or you can skip steps.
2. File→New Survey. This opens the Survey Tool
3. In the Survey Tool, Select File→ Add Tiles. This brings up the Load File dialogue
4. This time you will save a template so that you can re-use it for each GPR tile, which is loaded separately.
5. Select the following parameters for the GPR data:



6. Click Select Files
7. Browse to GPR files that make up tile N590E450 (they are in a directory by that name). Click Select Tiles
8. The GPR Reflection profiles will load one by one into the GPR Loader. Follow these steps as you go through the loader:
    a. Enter a Tile Name: N590E450. Click the Next button in the upper-left
    b. Bandpass Filter: First corner = 200 MHz, Second Corner = 800 MHz (there are high and low band pass filters). These should be automatically entered as defaults. Click Next

c. Fiduciary Mark Adjust: enter 2 for meters per mark. The columns on the left of this display give you the order of the files (1, 2, 3, etc), the start and end distances (start at 0, end at 20, for example), and then the number of marks. The rest of each line gives you the number of marks currently in each line. All full length profiles should have 11 marks. Those that do not are highlighted red. You can add and remove marks with the right mouse button, and slide them around with the left mouse button. If there are places where two marks are very close together or on top of each other, they are highlighted red. This editor is set up so you can figure out where the marks should be by looking at the data, without necessarily having field notes. I'm giving you the exact edits because you are just learning to use the software.
    i. You will need to add marks at the beginning of lines 5, 6, 7, 12 (I suggest you right click a short distance away from the start of the line to add each mark, then drag it all the way to the left with the left mouse button).
    ii. Add marks at the end of lines11,16, 18, 25-29
    iii. Delete extra marks in lines 27-29 and 33. You can easily pick these out by the spacing or by red highlights showing you places where there are double marks. Right click on a mark to delete it.
    iv. Lines 30-32 are missing data.
    v. Lines 30-32 are too short (instrument stopped recording for some reason), so you will have to edit the start and end points (column to the left of the mark counts). Lines 30 and 32 end at 12 meters. Line 31 starts at 16 (and ends at 20 meters).
    vi. If at some point you are worried that you messed things up and need to start over, just click reset marks.
d. Click Next
e. Auto Level: Check the box in the upper-right to skip this step, then click next.
f. Clip Soundings: Here you can clip off the top part of the signal so you can set time zero at the time that you think represents the ground surface. Click the mouse in the graph at the spot you want to use. You can click again and again to change the location, or hold the mouse button down and drag the line. You could also right-click to clip off part of the signal at the bottom, but we won't do that now. The graph

should look something like this:



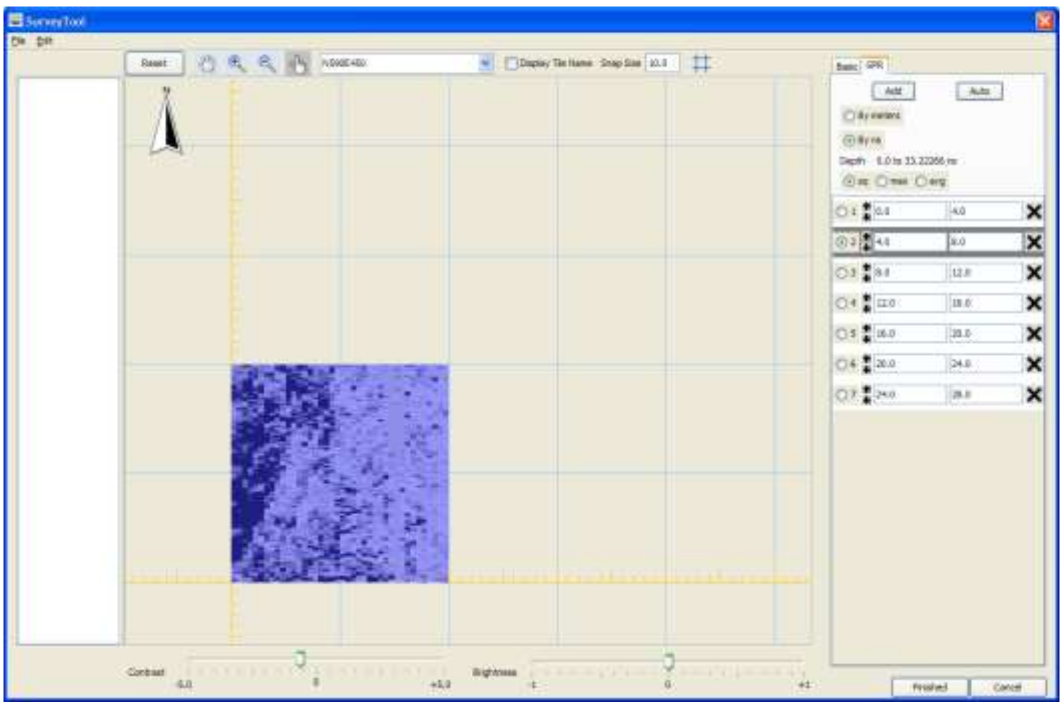
g. Click next
h. Remove Average Sounding (Background Removal). Click next to do this.
i. Gain adjust. In the interest of time, you can skip this step. Check the box next to skip in the upper-right and click next.
j. Depth Adjust: you can skip this too. Check the skip box and click next.
k. The input box comes up asking for a tile name. Since you already entered it at the beginning it will already be there (nice for those of us that are forgetful!). Just click ok. If you accidentally delete it, re-enter N590E450. After you click ok you will have to wait a few moments for the 3D cube to be created. It is creating a big file so may take a little while.
l. Click Done

9. Now we want to add this tile to the new survey. Click and drag it over to its proper place.
10. Enter the name “GPR” in the “Survey Name” Field in the upper right. Enter 0, 0, 0 for the longitude, Latitude, and azimuth. Enter False Easting 450, False Northing 590. Do not click finished yet (if you accidentally do, you can just click edit survey to get back here).
11. Click on the GPR tab in the right panel of the Survey tool. This is where we can create GPR slices, which will become separate bands in the GPR survey.
    a. Select “by ns” (by nanoseconds)
    b. Change the slicing method to “sq” for squared amplitudes.
    c. Click the auto button to generate a series of slices at equal intervals.

d. Enter from 0 ns to 28 ns; 7 slices, 4 ns thick

e. Be patient as slices are created.

f. Now you can click on the radio buttons next to the slices to view each one. Your window should look like this:

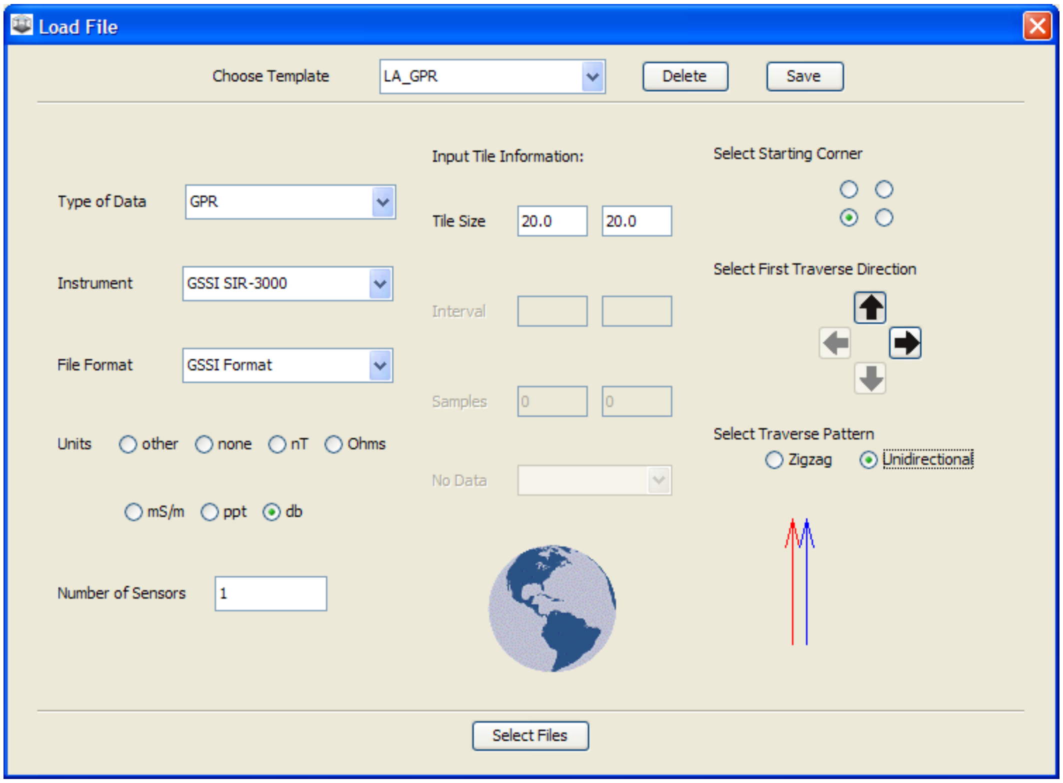


g. Click Finished

h. Click File→ Save Project

12. Now we want to process the remaining 3 GPR tiles. They are similar to the first one, but were collected by someone else, this time using the 3D mode with the SIR3000. This means that we need to select different options in the load file dialogue and then do similar processing to three sets of profiles. Once we do the first, we can click restart and do the other two using the exact same parameters. We can even copy some of the parameters from the first GPR cube to get started
    a. Make sure the GPR Survey is highlighted in the survey list. Click File→Edit Survey.
    b. In the Survey Tool, Select File→ Add Tiles. This brings up the Load File dialogue

c. Select the following parameters for the GPR data (same as before but unidirectional survey):



d. Click Select Files

e. Browse to GPR files that make up tile "Grid8_N590E470" (they are in a directory by that name). Select all 40 profiles and click Select Tiles

f. The GPR Reflection profiles will load one by one into the GPR Loader.

g. Follow these steps as you go through the loader:

  i. Enter a Tile Name: N590E470.

  ii. Now click File→Load Parameters and select the file N590E450.parameters (this will load the same parameters used for the last GPR file set). Click Open

  iii. You can now scroll through using these parameters, except you can handle the "Fiduciary Mark Adjust" part differently (much easier) and should double check the "Clip Soundings" setting.

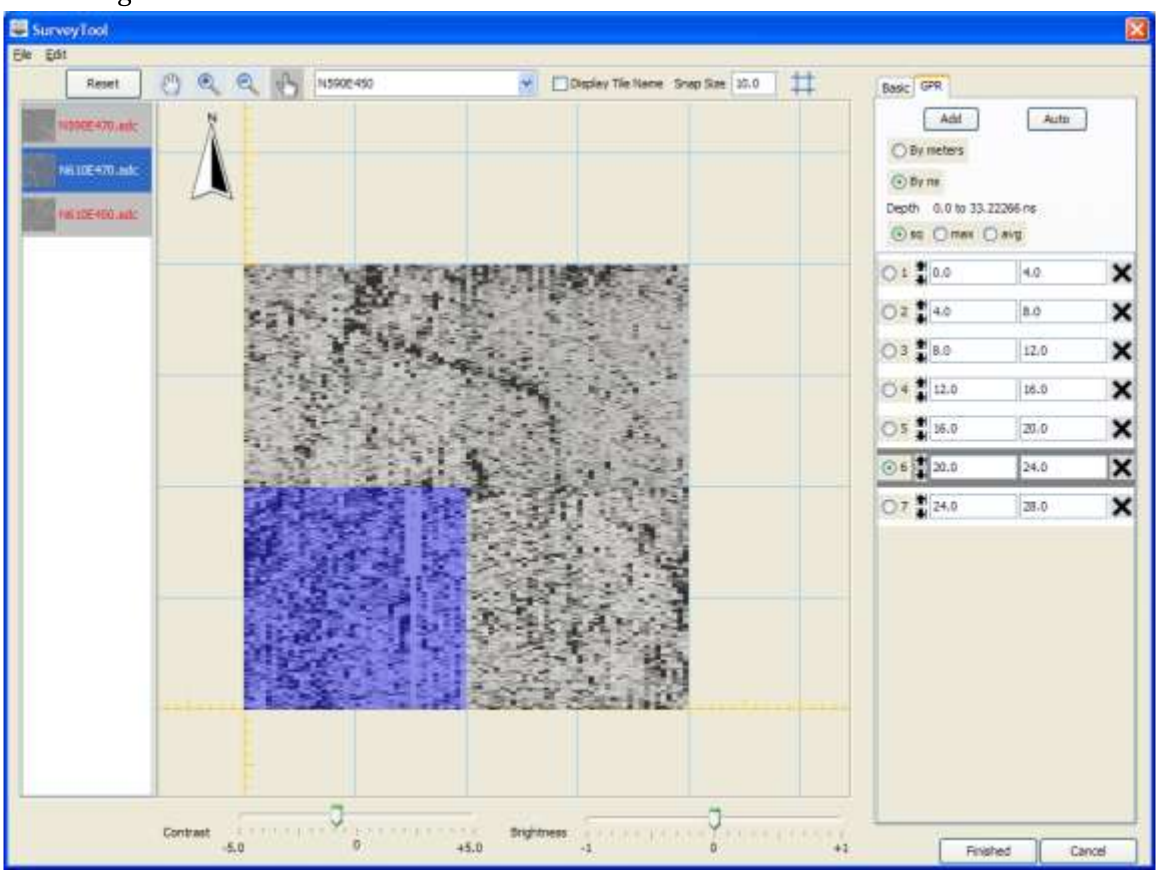
  iv. When you get to "Fiduciary Mark Adjust" you can just click "clear marks" and then Next. This will just stretch out all the lines to the length specified in the load file dialogue (20 meters). They are already nearly perfect in length due to the way they were collected.

  v. Don't forget to adjust the time depth for time zero ("clip soundings")

  vi. The input box comes up asking for a tile name. Since you already entered it at the beginning it will already be there (nice for those of us that are forgetful!). Just click ok. If you accidentally delete it, re-enter N590E470. After you click ok you will have to wait a few moments for the 3D cube to be created. It is creating a big file so may take a little while.

vii. Don NOT click Done. It is easiest to just click Restart here (upper left). It saves the same parameters that you just used, plus the same file loader settings.

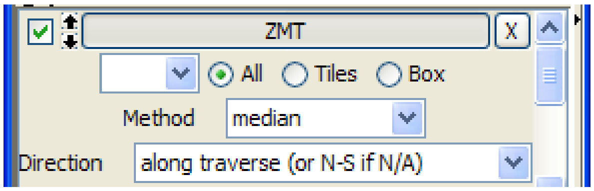
13. Now we want to process the last two GPR tiles, starting from where you left off above. The other two tiles are "Grid9_N610E470", and "Grid10_N610E450". For each one:
    a. Enter a Tile Name (corresponding to the file set you are processing).
    b. Click the Load Profiles button, browse to the GPR profiles for the tile you are going to process, select them all, and click Open.
    c. You can scroll through using the next button for every step, except you will have to click "clear marks" in the Fiduciary mark Adjust step. The time zero setting ("clip soundings") should be fine for Grid9, but will need to be increased for Grid 10.
    d. After the third GPR tile, remember to click Restart instead of Done.
    e. After the last GPR tile, click Done
14. Now we want to add these 3 tiles to the GPR survey. Click and drag them over. Each one will take a little while since it will be creating slices. When you are done it should look something like this:



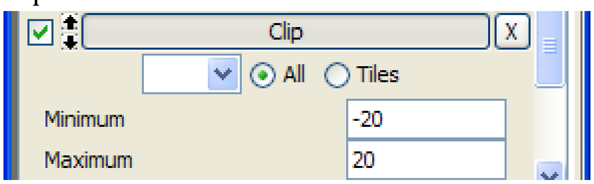
15. Enter the name "GPR" in the "Survey Name" Field in the upper right. Enter 0, 0, 0 for the longitude, Latitude, and azimuth. Enter False Easting 450, False Northing 590. Do not click finished yet (if you accidentally do, you can just click edit survey to get back here).
16. Click Finished
17. Click File→ Save Project

F. Processing the Magnetometry Data

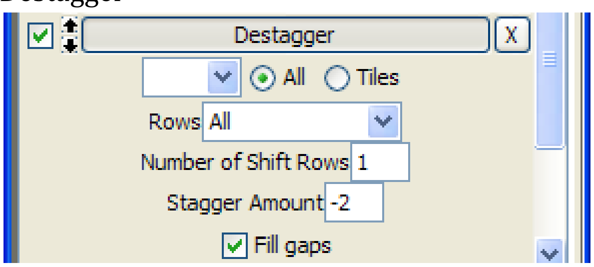
1. The Magnetometry data are in need of the destriping, clipping, destaggering, and smoothing. You can follow this recipe (it is exactly the same as used in the previous project, LosAdaesN610E470), or change it based on your own preferences and expertise. You may want to consult the draft user's manual to learn more about all the operations.
    a. Zero mean traverse



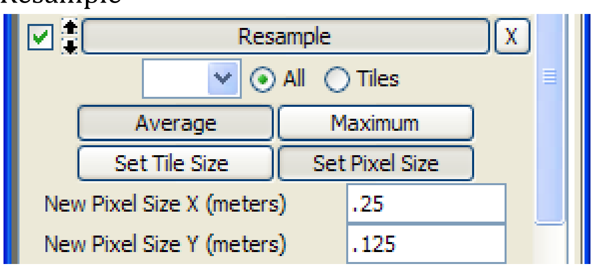
    b. Clip



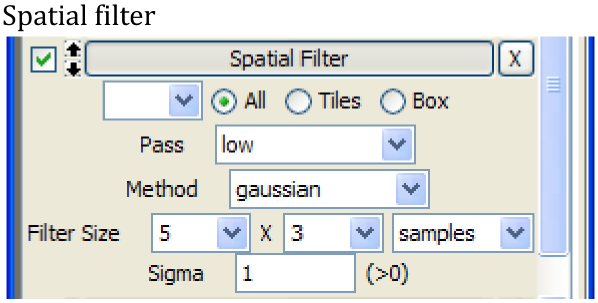
    c. Destagger



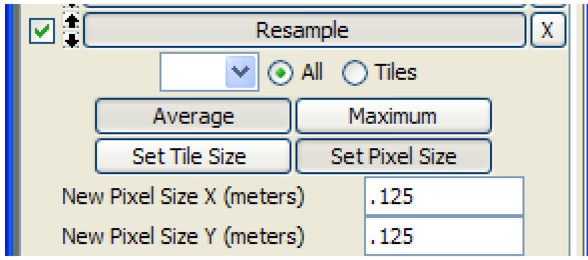
    d. Resample



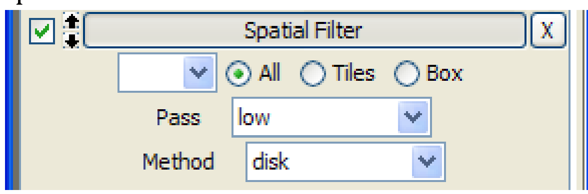
    e. Spatial filter



f. Resample



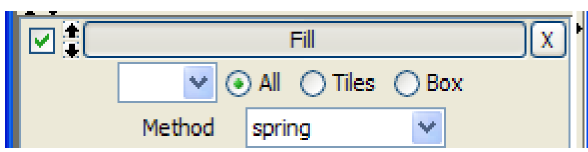
g. Spatial Filter



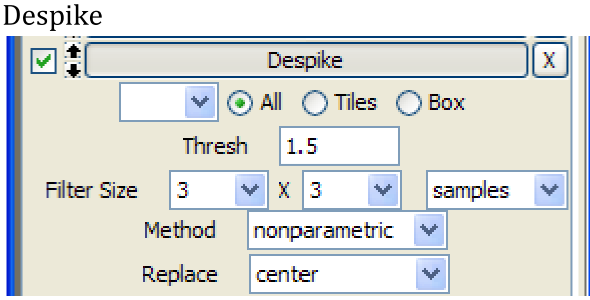
G. *Processing the Resistivity Data*

1. The Resistivity data are in need of the filling, despiking, edge matching ("Balance" is a way to automatically match edges that sometimes works), and smoothing. You can follow this recipe (it is exactly the same as used in the previous project, LosAdaesN610E470), or change it based on your own preferences and expertise. You may want to consult the draft user's manual to learn more about all the operations.

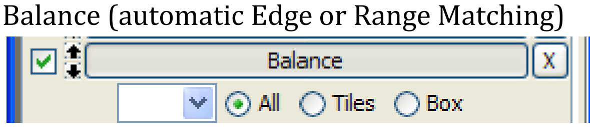
   a. Fill



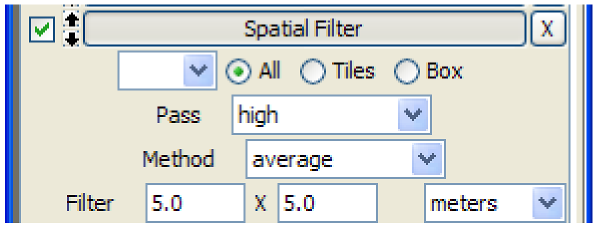
   b. Despike



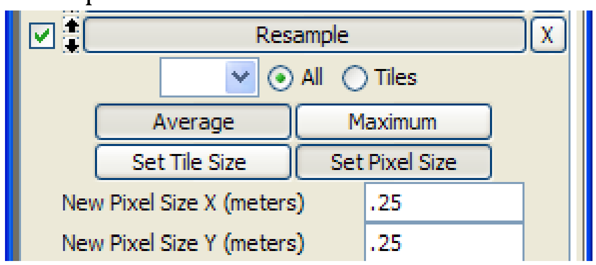
   c. Balance (automatic Edge or Range Matching)



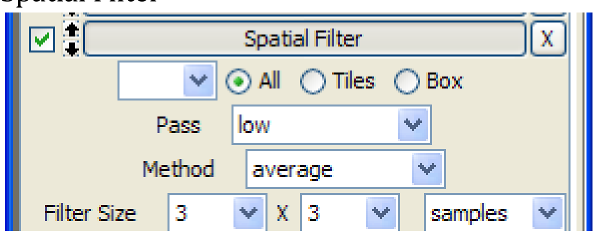
d. Spatial Filter



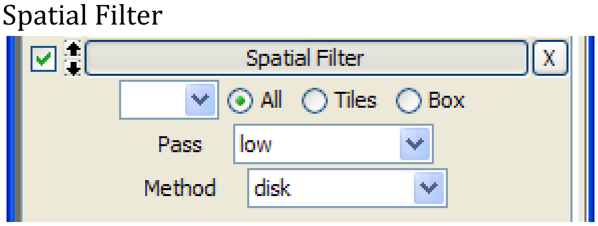
e. Resample



f. Spatial Filter

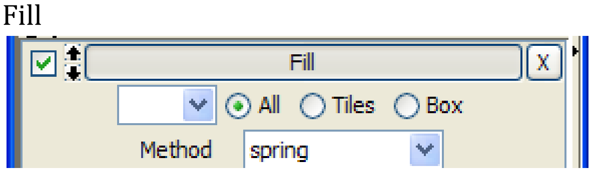


g. Spatial Filter



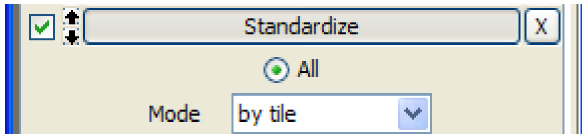
H. Processing the Magnetic Susceptibility Data

1. The MS data are in need of standardizing, despiking, detrending, range matching, and smoothing . You can follow this recipe (it is modified from the one used in the previous project, LosAdaesN610E470), or change it based on your own preferences and expertise. You may want to consult the draft user's manual to learn more about all the operations.
   a. Fill

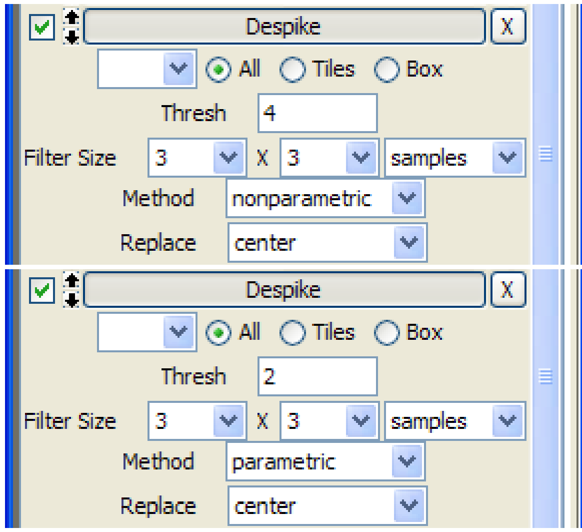


   b. Standardize (this equalizes differences between tiles, sort of like Geoplot's "Zero Mean Grid"). The data from the two different EM38 instruments are on very

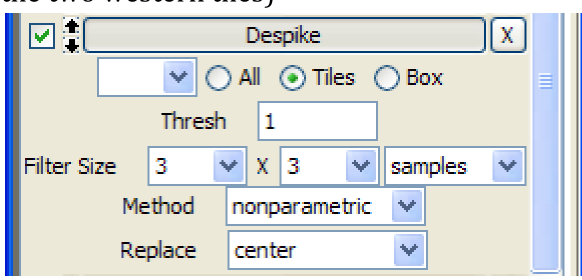
different scales.



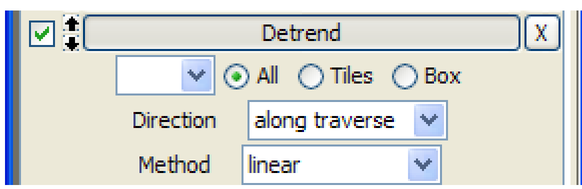
c. Despike (2 times)



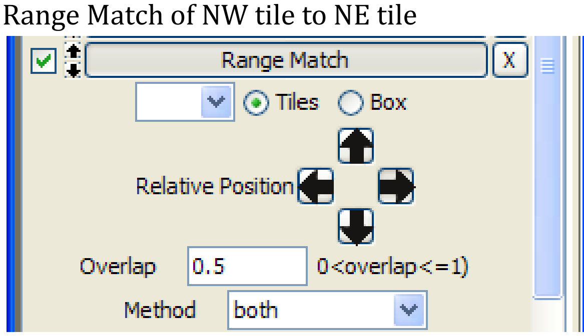
d. Despike on the two western tiles (select the “Tiles” Radio button and then click on the two western tiles)



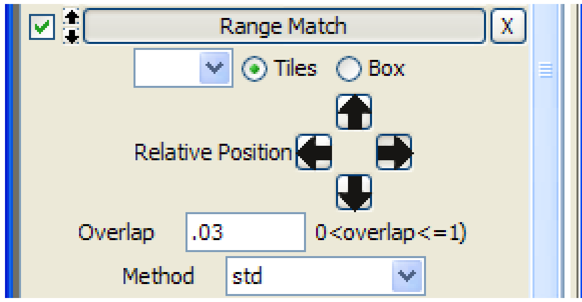
e. Detrend



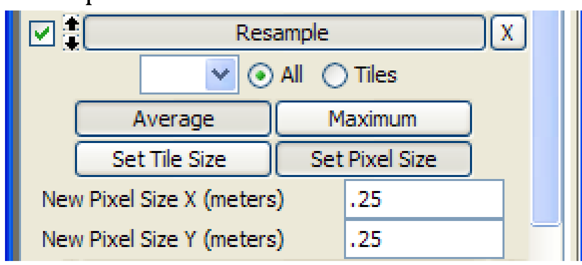
f. Range Match of NW tile to NE tile



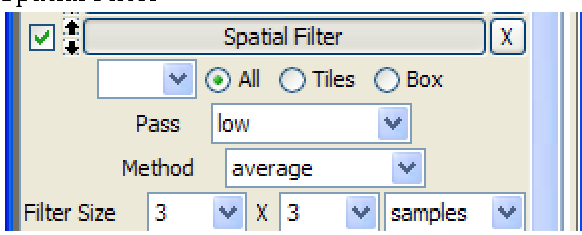
g. Range Match of SW tile to SE



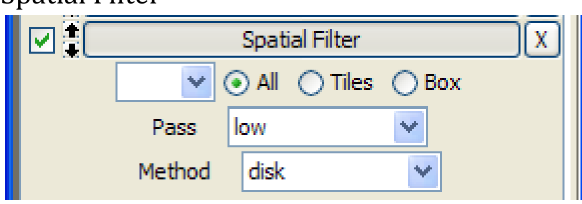
h. Resample



i. Spatial Filter



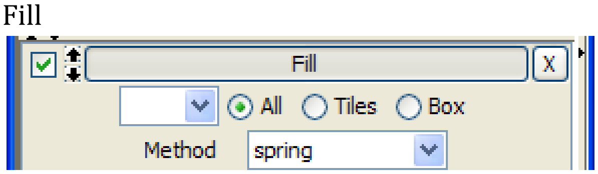
j. Spatial Filter



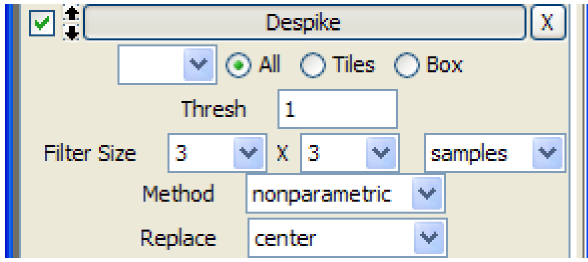
I. Processing the Conductivity Data

1. The Conductivity data are in need of the filling, despiking, and smoothing. You can follow this recipe (it is exactly the same as used in the previous project, LosAdaesN610E470), or change it based on your own preferences and expertise. You may want to consult the draft user's manual to learn more about all the operations.

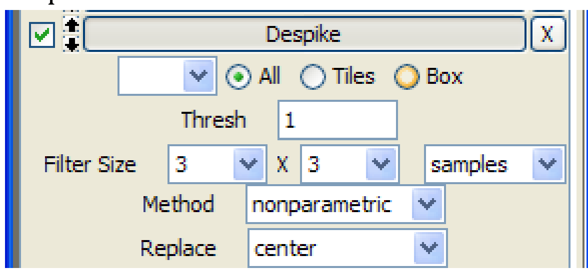
   a. Fill



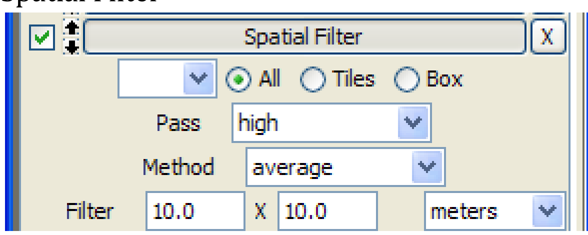
b. Despike



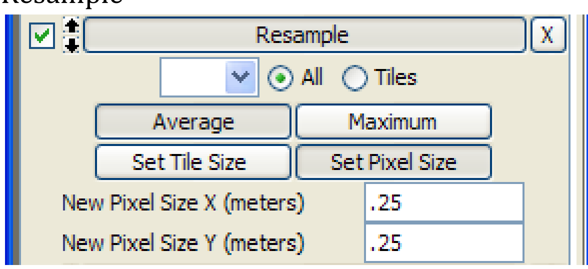
c. Despike



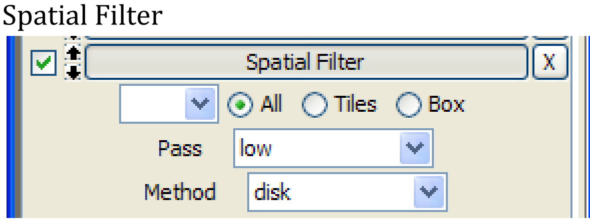
d. Spatial Filter



e. Resample



f. Spatial Filter

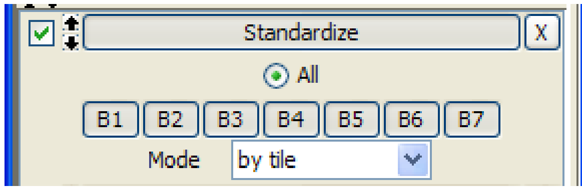


J. Processing the GPR Data

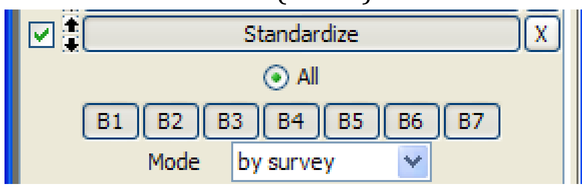
1. We will combine the GPR slices again using PCA. This time we will need to prepare the data since it was collected by two different instruments and needs to be standardized. Here's what to do:

a. Select (highlight) the GPR survey in the Survey List (left panel) and uncheck all the others.

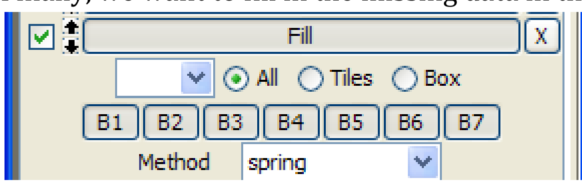
b. Add a Standardize Operation, and select “by tile” (this equalizes the tiles statistically, and for each GPR slice)



c. Now add another Standardize operation, this time we need to run it by survey so that all the GPR slices (bands) are standardized.

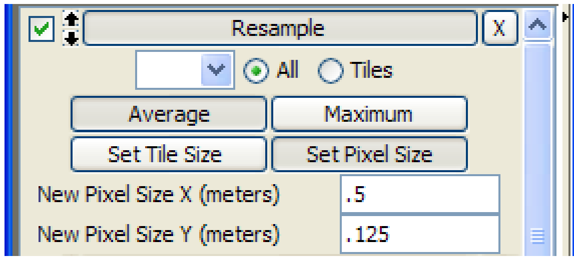


d. Finally, we want to fill in the missing data in the SW tile. Add a Fill operation.

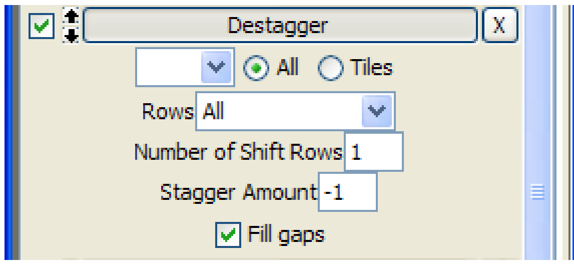


2. Now add a PCA operation by clicking on the button in the operations toolbar, or by selecting it from the Operations menu in the menu bar.
3. Click “Run Operation Stack”
4. You can look at the results in the new matlab window. The percent of variance explained by component 1 is not as high as before, but looking at it still shows that it summarizes the data well, with some anomalies in component 2. We can just use component 1 for this exercise.
5. Close the PCA Loadings window.
6. Click Tools→ Merge/Break Up Surveys. In the dialogue, check the box next to “Keep base layer resolution.” Enter a new Survey name: GPR PCA C1 (for GPR PCA Component 1). In the list of bands at the left, click on GPR B1. It will jump to the box at the right. This band will become Band 1 of the new survey. Click Finished. The new Survey is inserted at the bottom of the survey list.
7. The GPR PCA C1 data are in need of the resampling, destaggering, clipping, tile matching, and smoothing. You can follow this recipe (it is modified from the one used in the previous project, LosAdaesN610E470), or change it based on your own preferences and expertise. You may want to consult the draft user’s manual to learn more about all the operations.

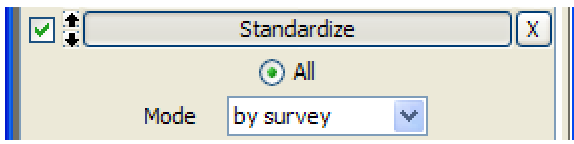
a. Resample



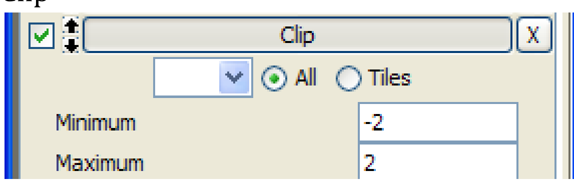
b. Destagger



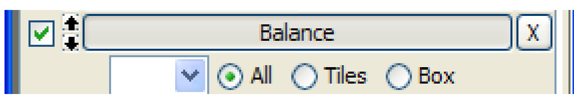
c. Standardize



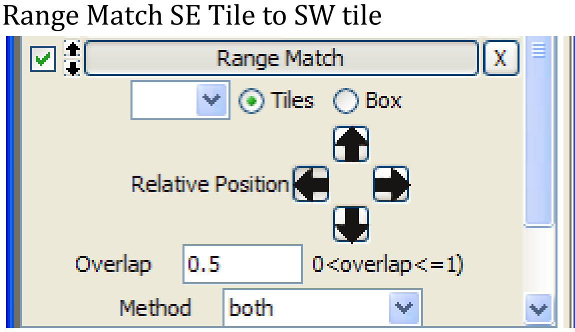
d. Clip



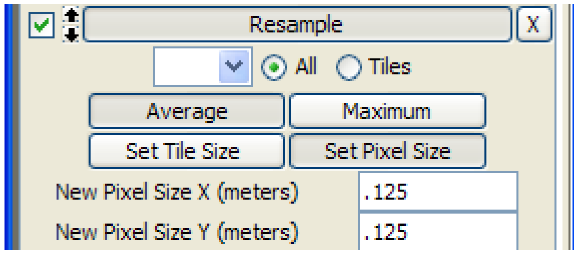
e. Balance



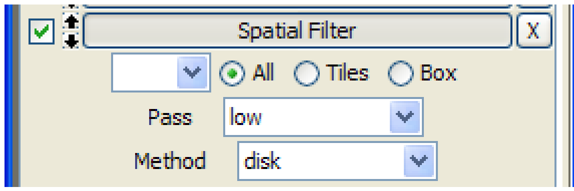
f. Range Match SE Tile to SW tile



g. Resample



h. Spatial Filter



K. Integrate the Geophysical Data

1. Using the techniques you learned Part II (beginning on page 4), integrate the geophysical data that you have processed. You can do exactly the same thing that was done in Part II, or try other methods.

L. Finish Deliverables

1. Export images (see instructions in Part I) or use print screen to show the results of your processing for each dataset (that you chose to do) and for your final fusion result
2. Report the time it took to process each dataset, and the time it took to integrate the results into at least one combined image.

Report

APPENDIX D: EVALUATION WORKSHEET FOR *ARCHAEOFUSION* ASSESSMENT 1

ArchaeoFusion Software Evaluation

Worksheet for reporting results
please send results to Eileen at eernenw@cast.uark.edu
if you have questions while you are working through the exercises and need help you can email Eileen or call her during office hours at 423-439-7655 (normally MWF 8:30-3, TTh 12-4 eastern time).

Part I: Objective 1. The case for using multiple Geophysical Methods

3) For each survey (Resistivity, Conductivity, Magnetic Susceptibility, Magnetometry, and Ground-penetrating radar slice 5, 16-20 ns), identify and number all anomalies using outlines or lines. Report which anomalies are interpreted to be cultural features and which are probably not cultural features. Give the final count of (a) all anomalies, (b) cultural feature anomalies, and (c) non-feature anomalies.

   --insert or attach survey images with anomalies identified and numbered—

   (a) Final Count of all anomalies = ________
   (b) Final Count of cultural feature anomalies = __________
   (c) Final count of non-feature anomalies = ____________

4) Using *ArchaeoFusion*, examine each anomaly previously identified and report whether the anomaly occurs in other datasets, and if so which ones. A table such as the following is suggested (one for each datasets). The "total" column gives the total number of other datasets in which the same or similar anomaly was found.

You can copy, modify and expand this table using table tools in word, or use another program and paste here or include as a separate file.

Resistivity Anomalies

Anomaly #	feature?	in mag?	in MS?	in Cond?	in GPR	total
1	Y			x	x	2
2	N					0
3	Y	x				1

Part II: Objectives 2-3. The case for Data Integration

3) Use *ArchaeoFusion* to integrate or fuse some of the Los Adaes datasets and save the results as images (you will learn to use PCA, the Band Calculator, and transparencies).

--insert or attach GPR PCA result—

--insert or attach screen capture (print screen) of translucent overlay result –

--insert or attach mathematical fusion using band calculator (sum3-5) –

4) Answer two multiple choice questions about your experience.

Please answer the following two multiple choice questions with reference to your experience from the exercises above (PCA of GPR slices, translucent overlays, and mathematical sum).

1) Integrating multiple datasets using ArchaeoMapper increased my ability to detect feature anomalies.

- *a* *Very true*
- *b* *Somewhat true*
- *c* *Neither true nor false*
- *d* *Somewhat false*
- *e* *Very false*

2) Integrating multiple datasets using ArchaeoMapper increased my ability to determine one or more characteristics of the feature anomalies (e.g., feature size, shape, depth, relative location to other anomalies, whether it was burned, presence of rock concentrations, etc.).

- *a* *Very true*
- *b* *Somewhat true*
- *c* *Neither true nor false*
- *d* *Somewhat false*
- *e* *Very false*

Part III: Objectives 5 & 7: The case for *ArchaeoFusion*

7) Time required to process and integrate at least two of the Los Adaes datasets in your software of choice (whatever you normally use, but not *ArchaeoFusion*). If you have experience with GPR and/or EM then we need you to choose these since this is the biggest strength of *ArchaeoFusion*. If you are only familiar with one method then that is ok, but try to use a second if you can. It would be best to get a detailed time log from you for each step of the way – e. g. how long it took to import and assemble the EM data, then to process it, then to preprocess the GPR data, slice it, assemble slices, process them, then integrate both together. If you do not know how to integrate multiple datasets then just state that this part could not be completed given your experience or limits to software.

--insert a summary of how much time it took you to process and integrate each chosen dataset--

8) Instructions for another person to replicate what you did. Think of this as creating an archive, which should contain raw data, finished results and a description of how the results were achieved. It is up to you how you want to do this. You might decide that you want to avoid being software-specific, or you could provide directions requiring a certain software. This is one of the challenges of creating a data archive. This can also be time consuming and so you should be realistic about how much detail you are able to provide given your time constraints. It could range from a copy of hand-written notes to a more formally written document. If your archive does not contain all of the details required for someone else to reproduce what you did then this is simply a reality and helps identify where geophysics software needs improvement.

   --insert or attach instructions and also email them to Eileen at eernenw@cast.uark.edu as soon as possible—

9) Time required for you to replicate another person's results by following their directions (please complete the other deliverables and you will be notified when there are instructions from someone else for this part.)

   --insert a summary of how much time it took you to process and integrate each chosen dataset following someone else's instructions and using your software of choice--

10) Time required for you to process and integrate the provided Los Adaes datasets using *ArchaeoFusion*. Again, try to provide a detailed time log like the one for your work in other software. Step-by-step instructions for this are provided below.

    --insert a summary of how much time it took you to process and integrate each chosen dataset--

11) Instructions for another person to replicate what you did using *ArchaeoFusion*. Just as for #2 above, think of this as an archive with raw data, final results, and a description of how the results were achieved. This could look something like what is provided for you in the instructions. *ArchaeoFusion* will eventually have an export function for creating an archive (will include raw data, results, and all processing steps), but it will not be ready for the first version. In the mean time, you can get data processing information for each survey by opening the "survey.operationlist" file in WordPad. This file is located in the project folder under surveys, and then the name of the survey. For example, for the res data used in the first project the file is here: LosAdaesProjectN610E470\Surveys\res\survey.operationlist. You can also save the operation stack and include it in the archive.

    --insert or attach instructions and also email them to Eileen at eernenw@cast.uark.edu—

12) Time required for you to replicate another person's results by following their directions and using *ArchaeoFusion* (again, you will be notified when directions are ready for you. First complete the other deliverables and submit them, so your instructions can be used by another participant).
*deliverables 3 and 6 cannot be done until we get deliverables 2 and 5 from other participants and send to you. Please complete 1, 2, 4, and 5 and send to us as soon as you can so we can send them to other participants to complete 3 and 6.

--insert a summary of how much time it took you to process and integrate each chosen dataset following someone else's instructions and using ArchaeoFusion--

APPENDIX E: EVALUATION PARTICIPANT RESULTS FOR *ARCHAEOFUSION* ASSESSMENT 1

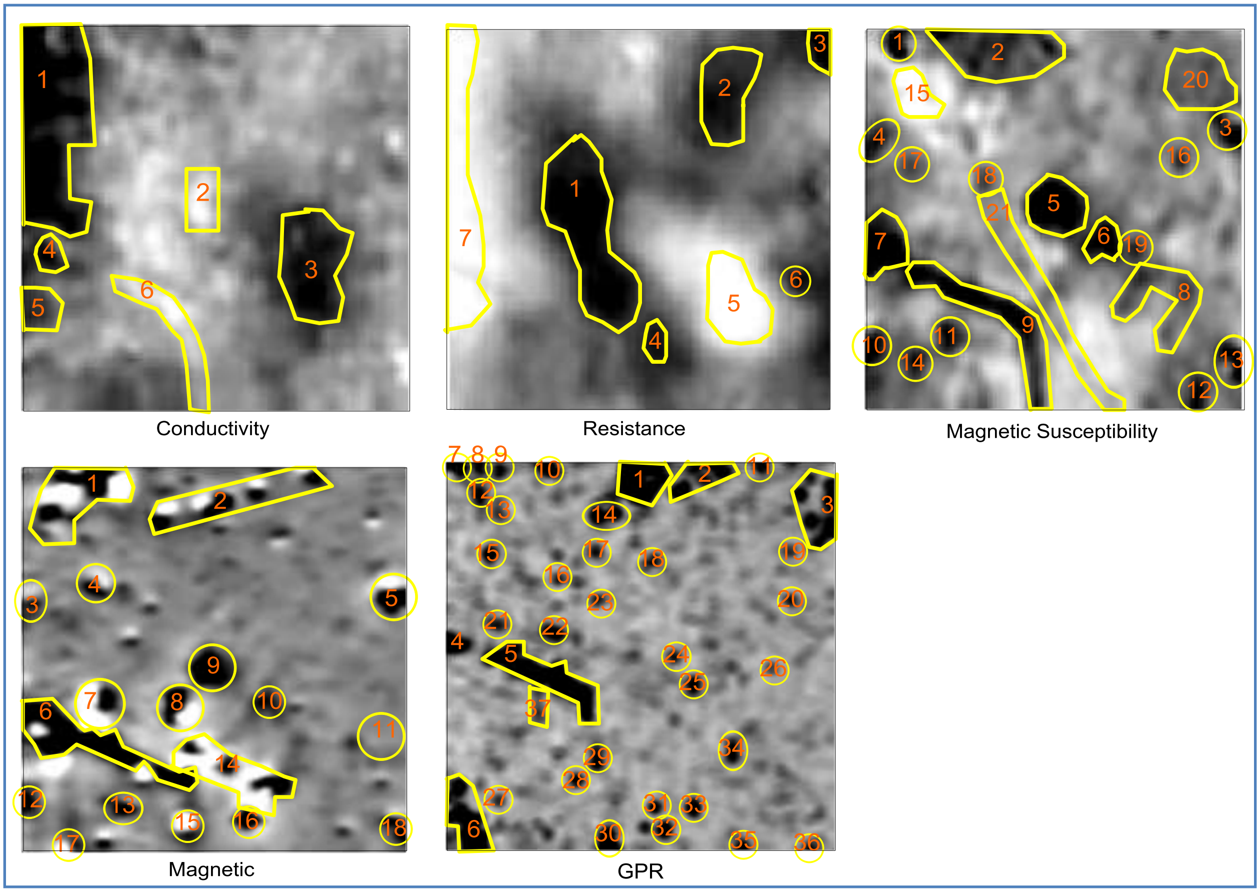
Participant 1:

Part I: Objective 1. The case for using multiple Geophysical Methods

5) For each survey (Resistivity, Conductivity, Magnetic Susceptibility, Magnetometry, and Ground-penetrating radar slice 5, 16-20 ns), identify and number all anomalies using outlines or lines. Report which anomalies are interpreted to be cultural features and which are probably not cultural features. Give the final count of (a) all anomalies, (b) cultural feature anomalies, and (c) non-feature anomalies. ***Comment: I did this rather hurriedly, but the results clearly demonstrate that use of more methods yields more anomalies and, very likely, detection of more features.***

   --insert or attach survey images with anomalies identified and numbered—

   (a) Final Count of all anomalies = __90_______
   (b) Final Count of cultural feature anomalies = ____25_______
   (c) Final count of non-feature anomalies = ____65_________



6) Using *ArchaeoFusion*, examine each anomaly previously identified and report whether the anomaly occurs in other datasets, and if so which ones. A table such as the following is suggested (one for each datasets). The “total” column gives the total number of other datasets in which the same or similar anomaly was found.

You can copy, modify and expand this table using table tools in word, or use another program and paste here or include as a separate file.

Resistivity Anomalies

Anomaly #	feature?	in mag?	in MS?	in Cond?	in GPR	total
1	Y			x	x	2
2	N					0
3	Y	x				1

Resistivity Anomalies

Anomaly #	Feature?	In Mag?	In MS?	In Cond?	In GPR?	Total
1	Y	N	Y?	N	N	1
2	N	N	N	N	N	0

3	Y	N	N	N	Y	1
4	N	N	Y?	N	N	1
5	N	N	Y	Y	N	2
6	Y	N	N	N	N	0
7	N	N	N	Y	N	1

Magnetic Anomalies

Anomaly #	Feature?	In Res?	In MS?	In Cond?	In GPR	Total
1	Y	Y	Y	Y	Y?	4
2	Y	N	N	N	Y	1
3	N	N	Y?	N?	N	1
4	N	Y	N	N?	N	1
5	N	N	Y?	N	N	1
6	Y	Y	N?	N?	N	1
7	N	Y	N	N	Y?	2
8	N	N	N	N	N?	0
9	N	N	Y	Y?	N	2
10	N	N	Y?	N	Y	2
11	N	N	N	N	N	0
12	N	N	Y	N	Y	2
13	N	N	N	N	N	0
14	N	N	N?	N	N	0
15	N	N	Y?	N?	Y	2
16	N	N	Y?	N	Y	2
17	N	N	N	N	Y	1
18	N	N	Y	N	N	1

Conductivity Anomalies

Anomaly #	Feature?	In Res?	In Mag?	In MS?	In GPR	Total
1	N	Y	N	Y	Y??	3
2	N	Y	N	Y	N	2
3	Y	N	N	Y?	N	1
4	N	Y	N	Y	N	2
5	N	Y	Y	N	N	2
6	Y	N	N	Y	N	1

Susceptibility Anomalies

Anomaly #	Feature?	In Res?	In Mag?	In Cond?	In GPR?	Total
1	Y	Y	Y	Y	Y	4
2	Y	Y	Y??	N	Y?	3
3	Y	N	N	N	N	0
4	N	Y	N	Y	N	2
5	Y	Y	N	Y	N	2
6	Y	N	Y	N	Y	2
7	Y	N	N	Y	N	1
8	Y	N	N	Y	N	1
9	Y	Y	N	Y	N	2
10	Y	Y	Y	N	Y	3
11	Y	N	N	N	N	0
12	Y	N	N	N	N	0
13	Y	N	N	N	N	0
14	Y	Y	Y	N	Y	3
15	N	Y	Y?	Y	Y	4
16	N	N	N	N	N	0
17	N	N	N	Y?	N	1
18	N	N	N	N	N?	0
19	N	N	N	Y	N	1
20	N	N	Y?	N	Y?	2

GPR Anomalies

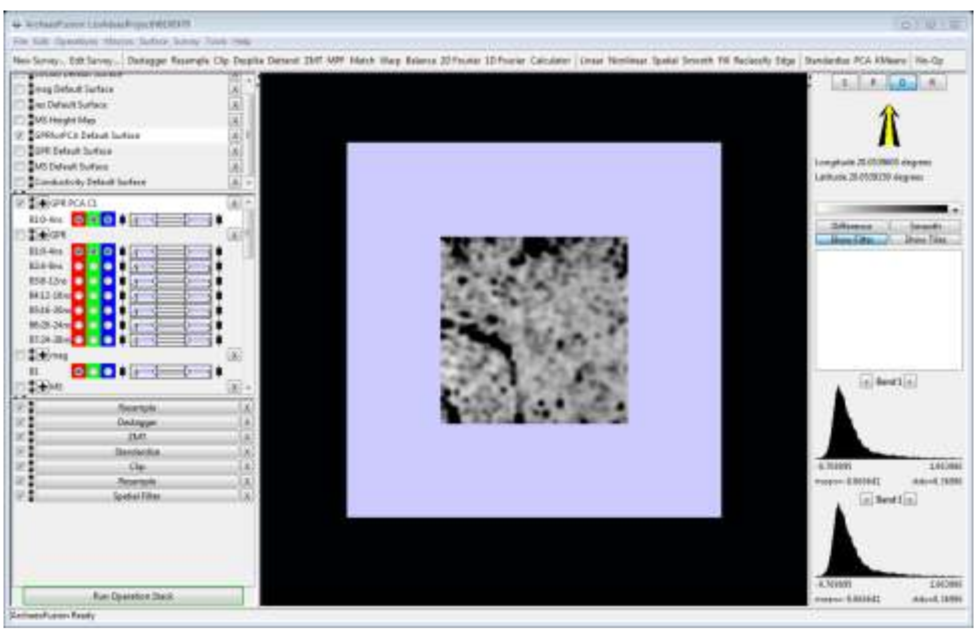
Anomaly #	Feature?	In Res?	In Mag?	In MS?	In Cond?	Total
1	Y	Y	Y	Y	N	3
2	N	Y	Y	N	N	2
3	Y	N	N	Y?	N	1
4	N	N	N	N	Y	1
5	Y	Y	N	Y?	Y	3
6	Y	N	Y	N	N	1
7	N	N	N	N	Y	1
8	N	Y	Y	Y	Y	4
9	N	N	Y	N	Y	2
10	N	Y	N	Y	N	2
11	N	N	N	N	N	0
12	N	Y	Y	Y	N	3
13	N	Y	Y	Y	Y	4
14	N	N	Y	Y?	N	2
15	N	N	N	N	N	0
16	N	N	N	N	N	0
17	N	N	Y	N	N	1
18	N	N	N	N	N	0
19	N	Y	N	N	N	1

20	N	N	N	N	N	0
21	N	N	N	N	N	0
22	N	N	N	N	N	0
23	N	N	N	N	N	0
24	N	N	N	Y	N	1
25	N	Y	N	Y	N	2
26	N	N	N	N	N	0
27	N	Y	N	Y	N	2
28	N	N	N	N	N	0
29	N	Y	N	Y	Y	3
30	N	Y	Y	N	Y	3
31	N	Y	N	N	N	1
32	N	Y	Y	N	N	2
33	N	N	Y	N	N	1
34	N	N	N	Y?	Y?	2
35	N	N	N	N	N	0
36	N	N	N	N	N	0
37	N	N	Y	N	Y	2
38	N	N	N	N	N	0
39	N	N	N	N	N	0
40	N	N	N	N	N	0

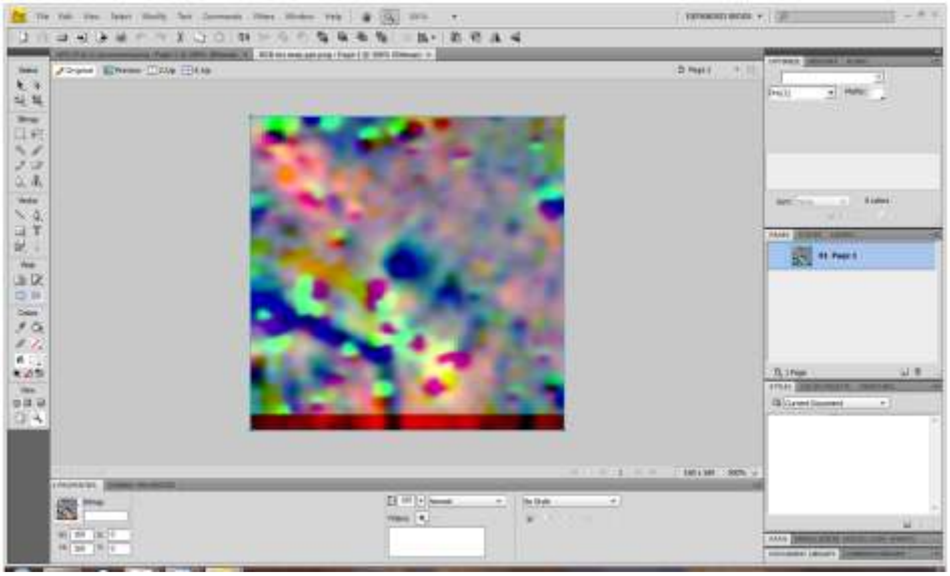
Part II: Objectives 2-3. The case for Data Integration

5) Use *ArchaeoFusion* to integrate or fuse some of the Los Adaes datasets and save the results as images (you will learn to use PCA, the Band Calculator, and transparencies).

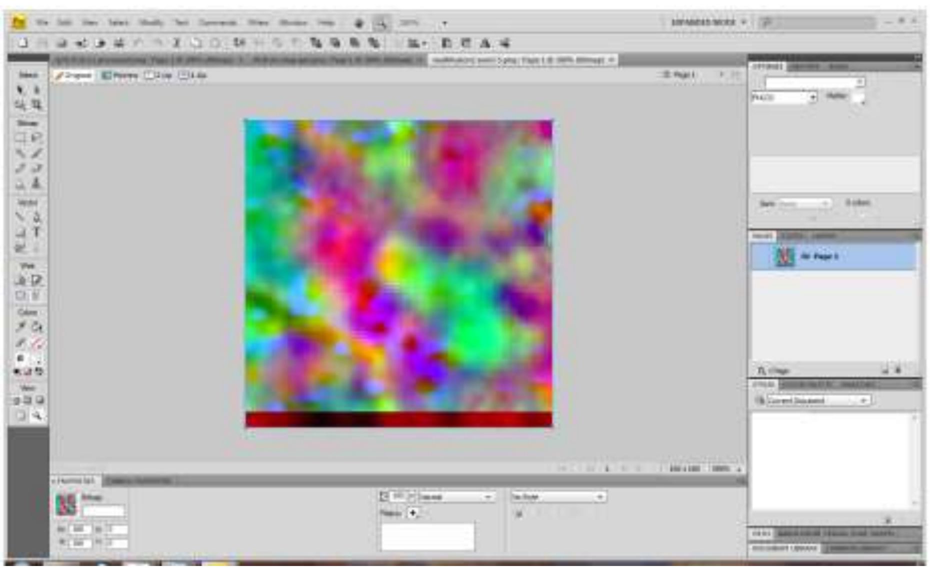
--insert or attach GPR PCA result—



--insert or attach screen capture (print screen) of translucent overlay result –



--insert or attach mathematical fusion using band calculator (sum3-5) –



6) Answer two multiple choice questions about your experience.

Please answer the following two multiple choice questions with reference to your experience from the exercises above (PCA of GPR slices, translucent overlays, and mathematical sum).

1) Integrating multiple datasets using ArchaeoMapper increased my ability to detect feature anomalies.

a Very true
b Somewhat true
c Neither true nor false
d Somewhat false
e Very false

2) Integrating multiple datasets using ArchaeoMapper increased my ability to determine one or more characteristics of the feature anomalies (e.g., feature size, shape, depth, relative location to other anomalies, whether it was burned, presence of rock concentrations, etc.).

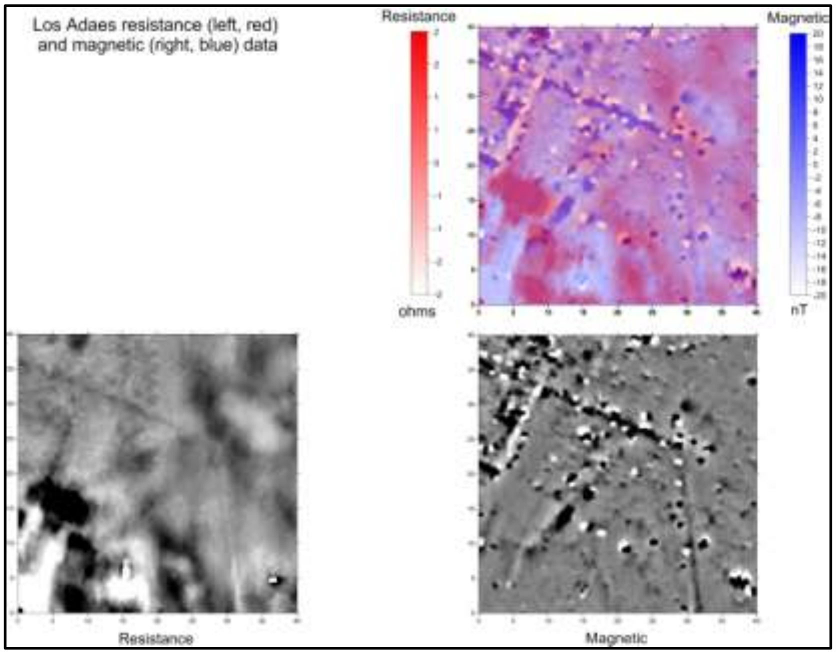
a Very true
b Somewhat true
c Neither true nor false
d Somewhat false
e Very false

Part III: Objectives 5 & 7: The case for *ArchaeoFusion*

13) Time required to process and integrate at least two of the Los Adaes datasets in your software of choice (whatever you normally use, but not *ArchaeoFusion*). If you have experience with GPR and/or EM then we need you to choose these since this is the biggest strength of *ArchaeoFusion*. If you are only familiar with one method then that is ok, but try to use a second if you can. It would be best to get a detailed time log from you for each step of the way – e. g. how long it took to import and assemble the EM data, then to process it, then to preprocess the GPR data, slice it, assemble slices, process them, then integrate both together. If you do not know how to integrate multiple datasets then just state that this part could not be completed given your experience or limits to software.

--insert a summary of how much time it took you to process and integrate each chosen dataset—

40 minutes to load magnetic and resistance data, process those data in Geoplot. About one-half of this time was spent on file management issues (importing data into Geoplot).



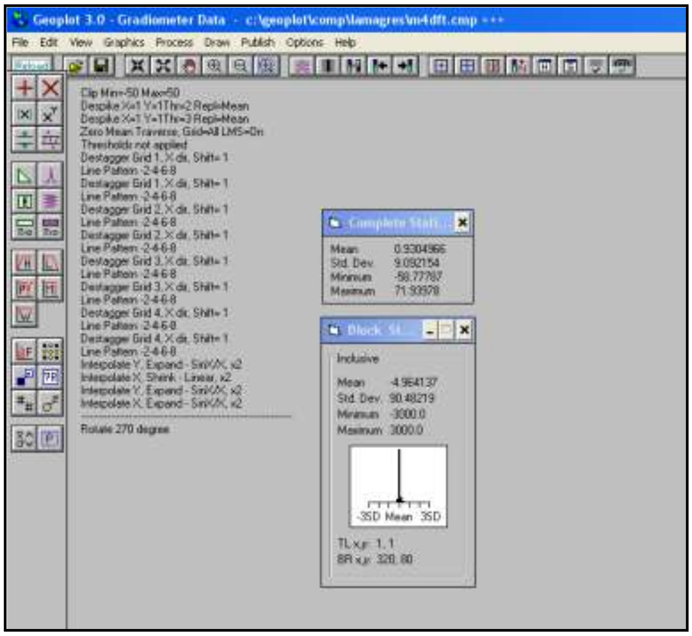
I made a copy of each map in Surfer 9.11. Copies can't be manipulated so I used them as gray scale images. I then altered the color scales and transparency, then simply dragged on top of the other.

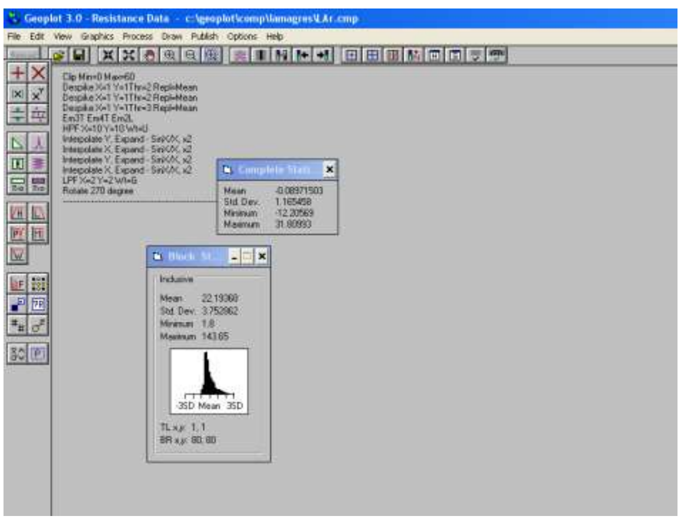
This required about 15 minutes. Note, however, that this is the <u>only</u> kind of "fusion" I know how to do other than with ArchaeoFusion.

(Note: Total time = about 55 minutes.)

14) Instructions for another person to replicate what you did. Think of this as creating an archive, which should contain raw data, finished results and a description of how the results were achieved. It is up to you how you want to do this. You might decide that you want to avoid being software-specific, or you could provide directions requiring a certain software. This is one of the challenges of creating a data archive. This can also be time consuming and so you should be realistic about how much detail you are able to provide given your time constraints. It could range from a copy of hand-written notes to a more formally written document. If your archive does not contain all of the details required for someone else to reproduce what you did then this is simply a reality and helps identify where geophysics software needs improvement.

--insert or attach instructions and also email them to Eileen at eernenw@cast.uark.edu as soon as possible—





The screen-print images above provide the metadata on how Los Adaes magnetic data were processed. I had several false starts in importing the magnetic data into Geoplot, although I had done that numerous times (but not recently). The delays were simple file management issues. After processing in Geoplot, I used the following Geoplot commands to export the data into Surfer 9.11: File - Export current data - (set Export file format to Surfer Ascii) – Input Export File Name – OK. In Surfer: File – new – plot – Map –new –image map – browse to Geoplot expdata – select export file name - double click on image – select color preferences – select data data minimum and maximum – ok – check interpolate pixels and show color scale – OK – select image and manipulate size – double click on color bar and choose preferences – Draw – text –click on screen – input text – click –drag text to desired location.

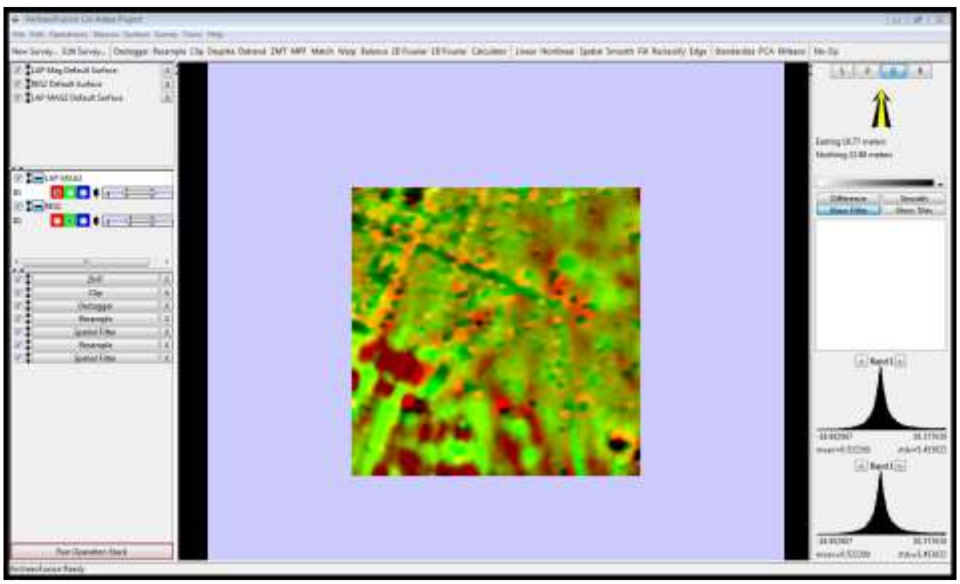
Time required to prepare these metadata: Only about 10 minutes.

15) Time required for you to replicate another person's results by following their directions (please complete the other deliverables and you will be notified when there are instructions from someone else for this part.)

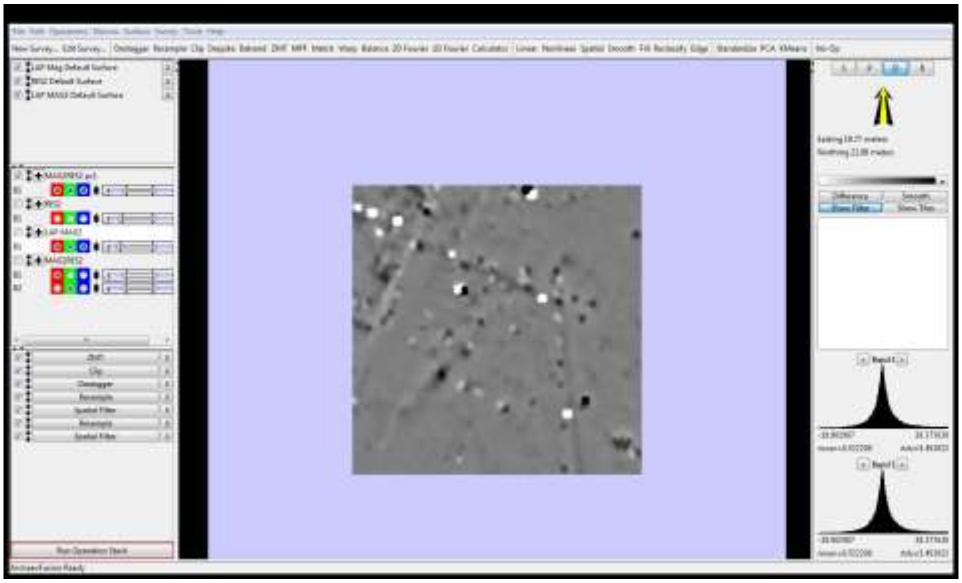
--insert a summary of how much time it took you to process and integrate each chosen dataset following someone else's instructions and using your software of choice--

16) Time required for you to process and integrate the provided Los Adaes datasets using *ArchaeoFusion*. Again, try to provide a detailed time log like the one for your work in other software. Step-by-step instructions for this are provided below.

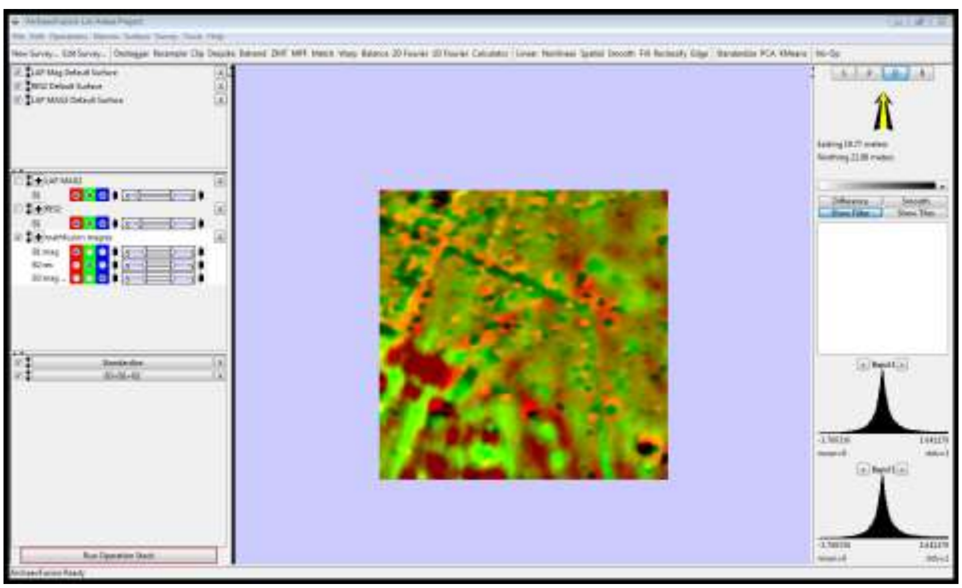
--insert a summary of how much time it took you to process and integrate each chosen dataset--



Above is a translucent overlay of the magnetic and resistance data, each processed as recommended. The magnetic data are shown as red and the resistance data are shown as green. Areas of strong overlay are orange. This required only about 5 minutes and could have been done faster if I had more experience with AF.



Results of a PCA of the magnetic and resistance data processed as recommended. I created a new dataset with two bands, one magnetic and one resistance. I then did a PCA on the unprocessed 2-band data. Finally, I used the operations stack that had been used previously on the magnetic data. Nearly all of the variability is explained by the first PC, and that PC is comprised almost entirely of the magnetic data. Thus, the PCA-fused data has the characteristics primarily of the magnetic data, but the image appears to be less informative than the magnetic data alone. This took about 12 minutes, as I had to reread the instructions for Section 2. I'm not sure that this fusion makes sense.



Above is a fusion done by simply adding the magnetic and resistance data, processed as recommended. This required 17 minutes, only because I had to reread the directions, etc. I probably could have done it in 3 or 4 minutes. Note that I did not correct the data offset. That would have added very little time, but I forgot to do it.

17) Instructions for another person to replicate what you did using *ArchaeoFusion*. Just as for #2 above, think of this as an archive with raw data, final results, and a description of how the results were achieved. This could look something like what is provided for you in the instructions. *ArchaeoFusion* will eventually have an export function for creating an archive (will include raw data, results, and all processing steps), but it will not be ready for the first version. In the mean time, you can get data processing information for each survey by opening the "survey.operationlist" file in WordPad. This file is located in the project folder under surveys, and then the name of the survey. For example, for the res data used in the first project the file is here: LosAdaesProjectN610E470\Surveys\res\survey.operationlist. You can also save the operation stack and include it in the archive.

--insert or attach instructions and also email them to Eileen at [eernenw@cast.uark.edu—](mailto:eernenw@cast.uark.edu)

18) Time required for you to replicate another person's results by following their directions and using *ArchaeoFusion* (again, you will be notified when directions are ready for you. First complete the other deliverables and submit them, so your instructions can be used by another participant).

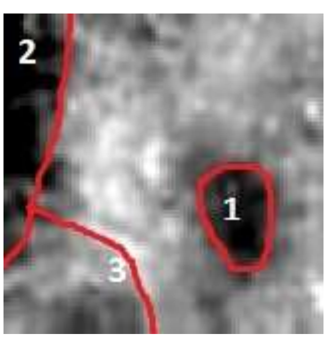
*deliverables 3 and 6 cannot be done until we get deliverables 2 and 5 from other participants and send to you. Please complete 1, 2, 4, and 5 and send to us as soon as you can so we can send them to other participants to complete 3 and 6.

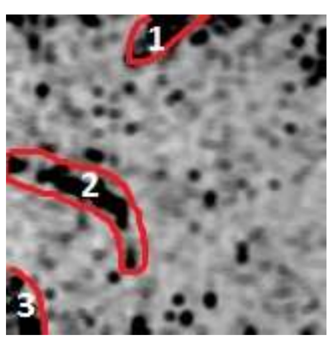
--insert a summary of how much time it took you to process and integrate each chosen dataset following someone else's instructions and using ArchaeoFusion--

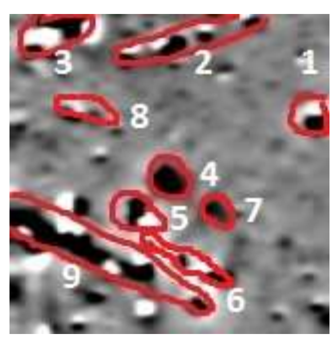
Participant 2:

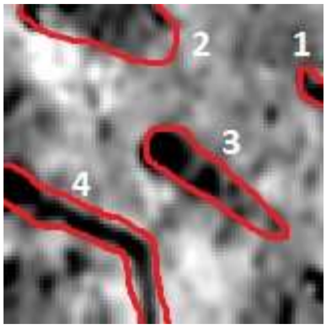
Part I: Objective 1. The case for using multiple Geophysical Methods

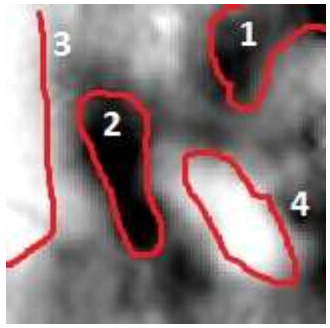
- For each survey (Resistivity, Conductivity, Magnetic Susceptibility, Magnetometry, and Ground-penetrating radar slice 5, 16-20 ns), identify and number all anomalies using outlines or lines. Report which anomalies are interpreted to be cultural features and which are probably not cultural features. Give the final count of (a) all anomalies, (b) cultural feature anomalies, and (c) non-feature anomalies.











(a) Final Count of all anomalies = ___23_______
(b) Final Count of cultural feature anomalies = ______14______
(c) Final count of non-feature anomalies = _______9_______

- Using *ArchaeoFusion*, examine each anomaly previously identified and report whether the anomaly occurs in other datasets, and if so which ones. A table such as the following is suggested (one for each datasets). The "total" column gives the total number of other datasets in which the same or similar anomaly was found.

Conductivity

Anomaly #	feature?	in mag?	in MS?	in Res?	in GPR	total
1	Y			x		1
2	Y			x		1
3	Y	x	x		x	3

Radar

Anomaly #	feature?	in mag?	in MS?	in Cond?	in Res	total
1	Y					0
2	Y	x	x	x		3
3	Y					0

Mag

Anomaly #	feature?	in res?	in MS?	in Cond?	in GPR	total
1	N					0
2	N					0
3	N					0
4	Y		x			1
5	N					0
6	N					0
7	Y					0
8	N					0
9	Y		x	x	x	3

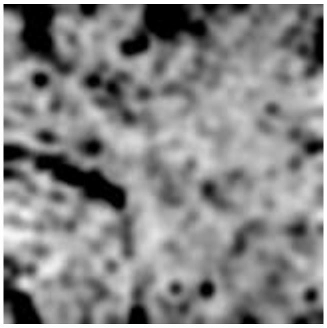
MS						
Anomaly #	feature?	in mag?	in Res?	in Cond?	in GPR	total
1	N					0
2	N					0
3	Y	x				1
4	Y	x			x	2

Resistivity						
Anomaly #	feature?	in mag?	in MS?	in Cond?	in GPR	total
1	Y					0
2	Y					0
3	Y			x		1
4	Y					0

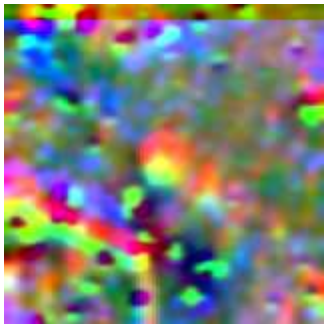
Part II: Objectives 2-3. The case for Data Integration

Use *ArchaeoFusion* to integrate or fuse some of the Los Adaes datasets and save the results as images (you will learn to use PCA, the Band Calculator, and transparencies).

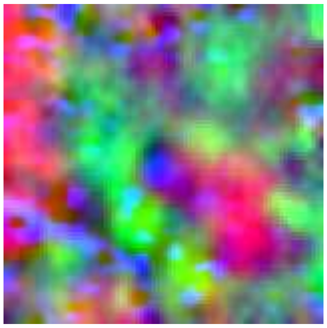
--insert or attach GPR PCA result—



--insert or attach screen capture (print screen) of translucent overlay result –



--insert or attach mathematical fusion using band calculator (sum3-5) –



Answer two multiple choice questions about your experience.

Please answer the following two multiple choice questions with reference to your experience from the exercises above (PCA of GPR slices, translucent overlays, and mathematical sum).

1) Integrating multiple datasets using ArchaeoMapper increased my ability to detect feature anomalies.

c Neither true nor false

2) Integrating multiple datasets using ArchaeoMapper increased my ability to determine one or more characteristics of the feature anomalies (e.g., feature size, shape, depth, relative location to other anomalies, whether it was burned, presence of rock concentrations, etc.).

b Somewhat true

Part III: Objectives 5 & 7: The case for *ArchaeoFusion*

Comments

1 I am using 64 bit Windows 7 on a new Pro HP ProBook 6540b laptop. All latest Windows patches applied, latest AF jar file installed.

2 There does not appear to be an Undo button or Go Back to Previous Stage button – I reverted to closing the program and restarting.

3 Export Survey is on the Survey menu, not Tools menu.

4 The palettes do not always update every time correctly.

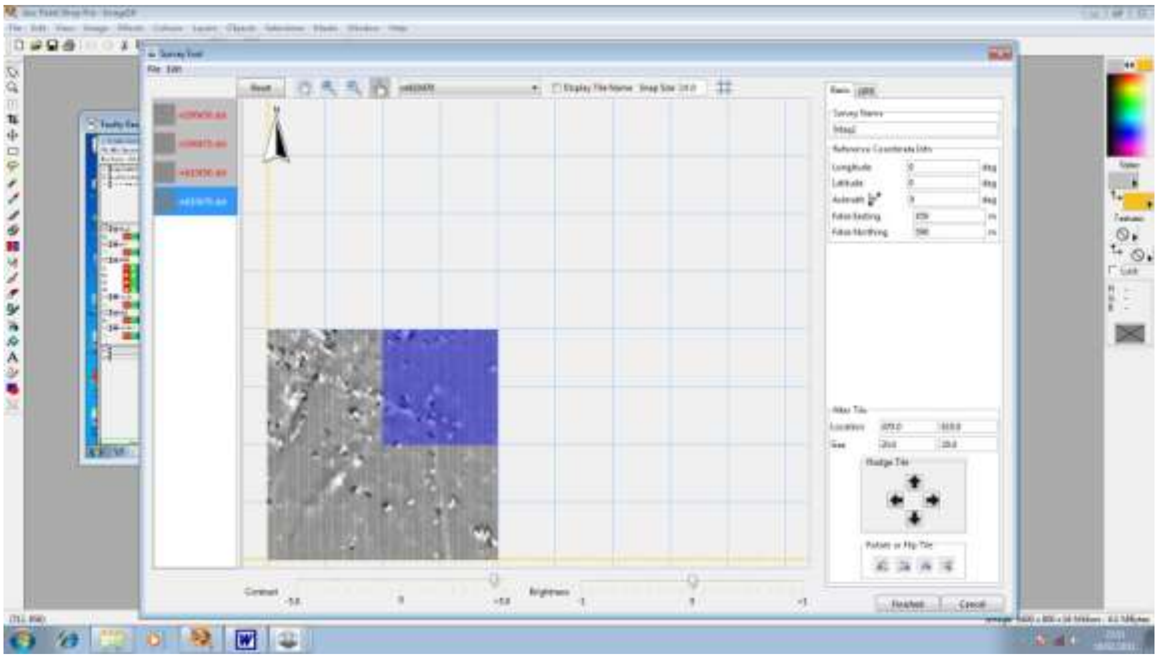
5 The PCR window and Create Survey windows had to be expanded to see all the data and buttons at the bottom.

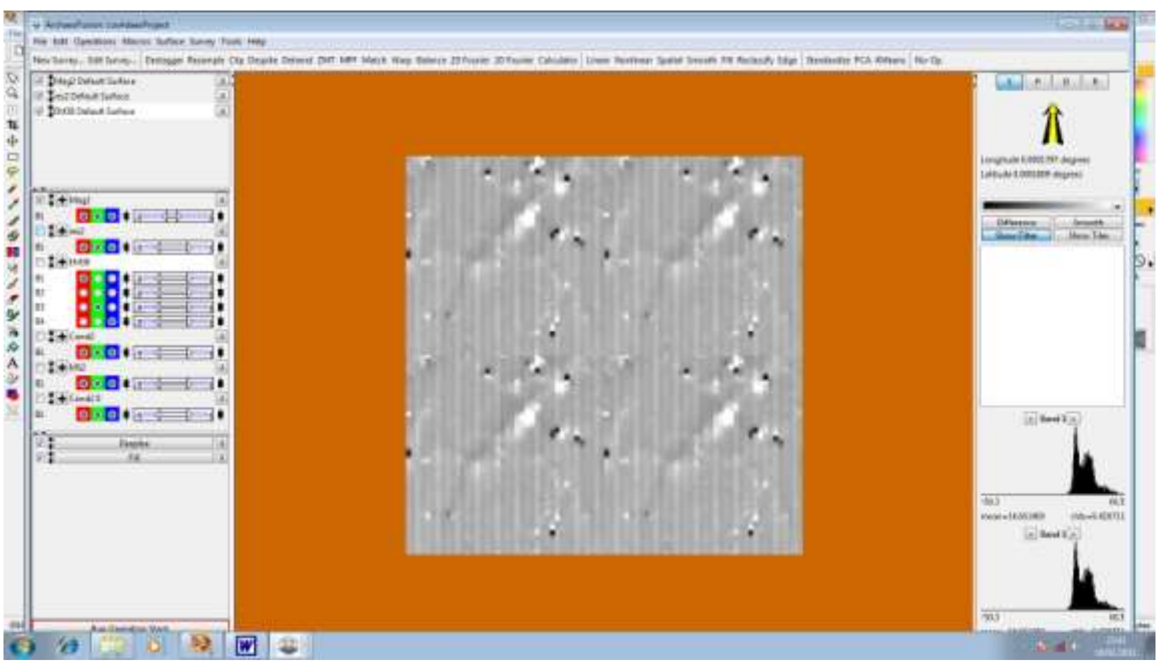
6 Even though the data sets were small, operations seemed to take an appreciable time.

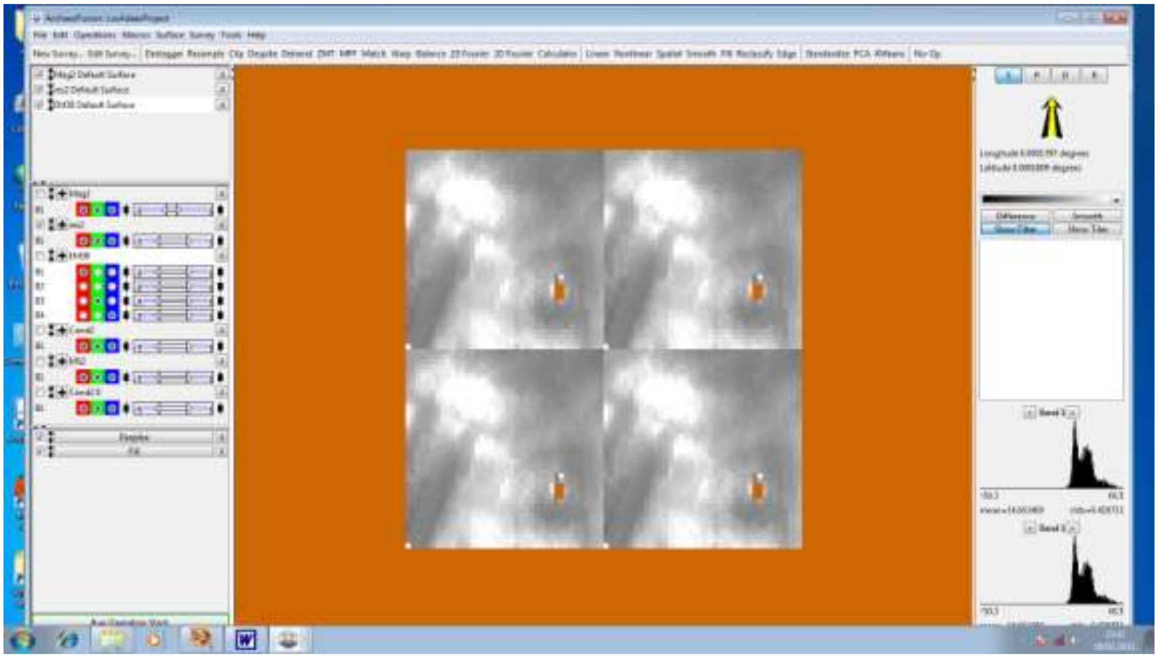
7 Starting a new project still left histograms from the previous project in the bottom right hand corner.

8 Although I could assemble the data tiles correctly on screen (see below) when Finished was pressed and the program returned to normal view only one tile was replicated four times (see below). This happened for all the data sets.

9 I could make a list of tasks and pressing Run Tasks seemed to make them happen (saw the operation complete message) but nothing changed on screen. I discovered that if you exited AF and reloaded data then the operations would then take place if I reran the tasks.

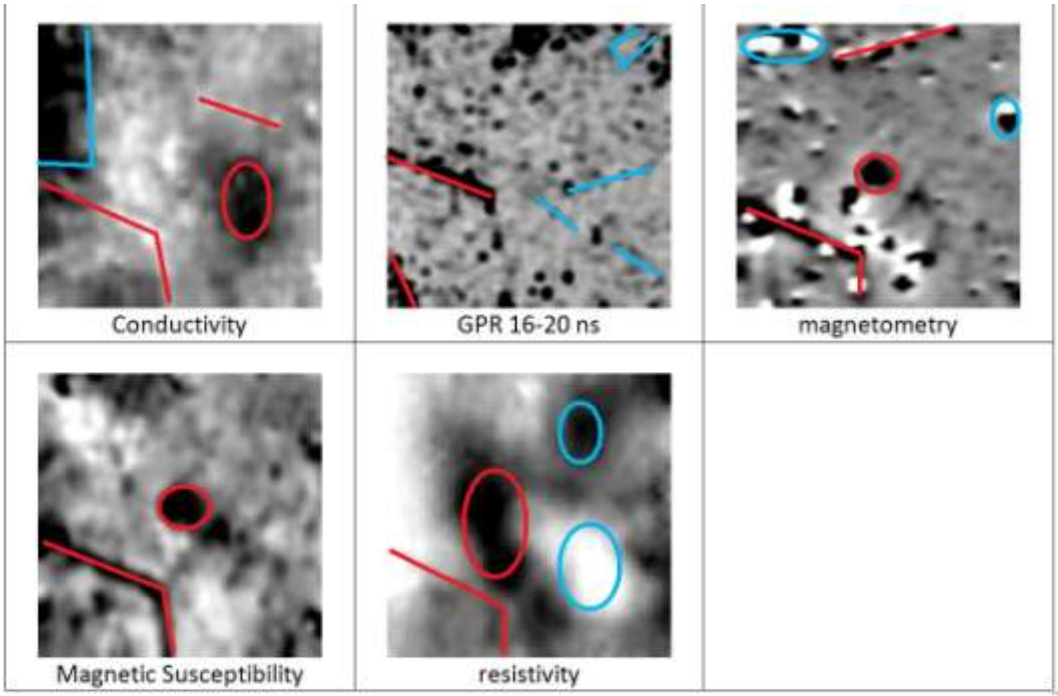






Participant 3:

Part I, d



Red – Cultural
Blue – Non cultural

Part II D
1. A
2. A

Part III
1) Time required to process and integrate at least two of the Los Adaes datasets in your software of choice (whatever you normally use, not *ArchaeoFusion*).
GPR_Slice, 2 hours for GPR, 1 hr for EM and overlay

4) Time required for you to process and integrate the provided Los Adaes datasets using *ArchaeoFusion. Approximately 8 hours (following the instruction worksheet) and the GPR data never got out of a badly pixilated image*

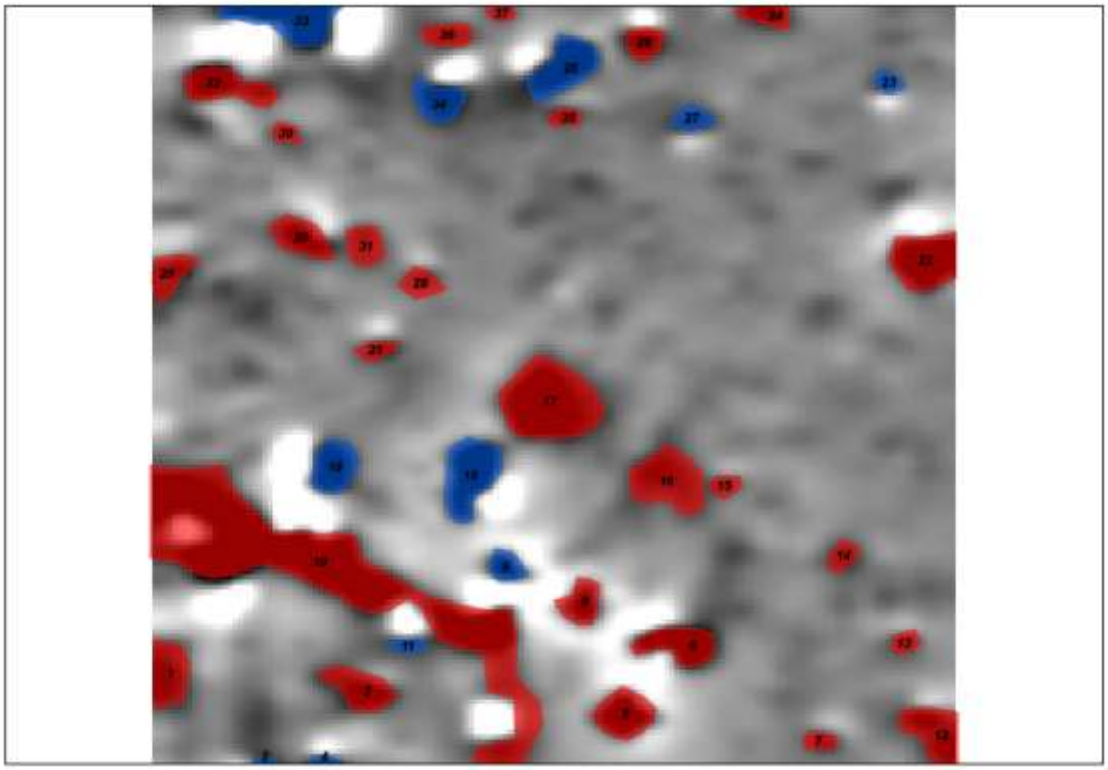
Participant 4:

Part I: Objective 1. The case for using multiple Geophysical Methods

7) For each survey (Resistivity, Conductivity, Magnetic Susceptibility, Magnetometry, and Ground-penetrating radar slice 5, 16-20 ns), identify and number all anomalies using outlines or lines. Report which anomalies are interpreted to be cultural features and which are probably not cultural features. Give the final count of (a) all anomalies, (b) cultural feature anomalies, and (c) non-feature anomalies.

Red colour is considered an anthropogenic anomaly. Blue is uncertain, natural, metal or noise.

Magnetometer

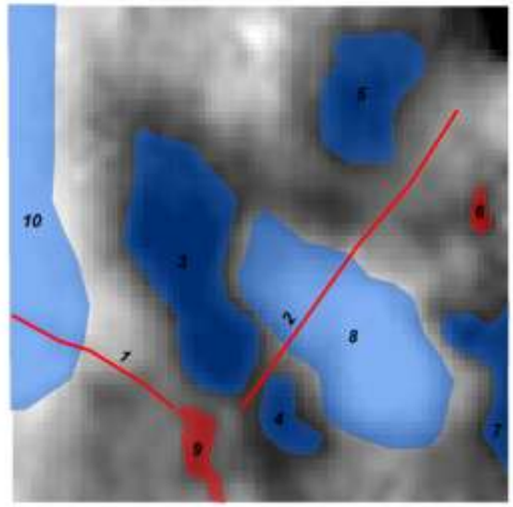


Number	Feature
1	Yes
2	No
3	Yes
4	No
5	Yes
6	Yes
7	Yes

8	Yes
9	No
10	Yes
11	No
12	Yes
13	Yes
14	Yes
15	Yes
16	Yes
17	Yes
18	No
19	No
20	Yes
21	Yes
22	Yes
23	No
24	Yes
25	No
26	Yes
27	No
28	No
29	Yes
30	Yes
31	Yes
32	Yes
33	No
34	No
35	Yes
36	Yes
37	Yes
38	No
39	Yes

(a) Final Count of all anomalies = __39_______
(b) Final Count of cultural feature anomalies = ___26________
(c) Final count of non-feature anomalies = _____13________

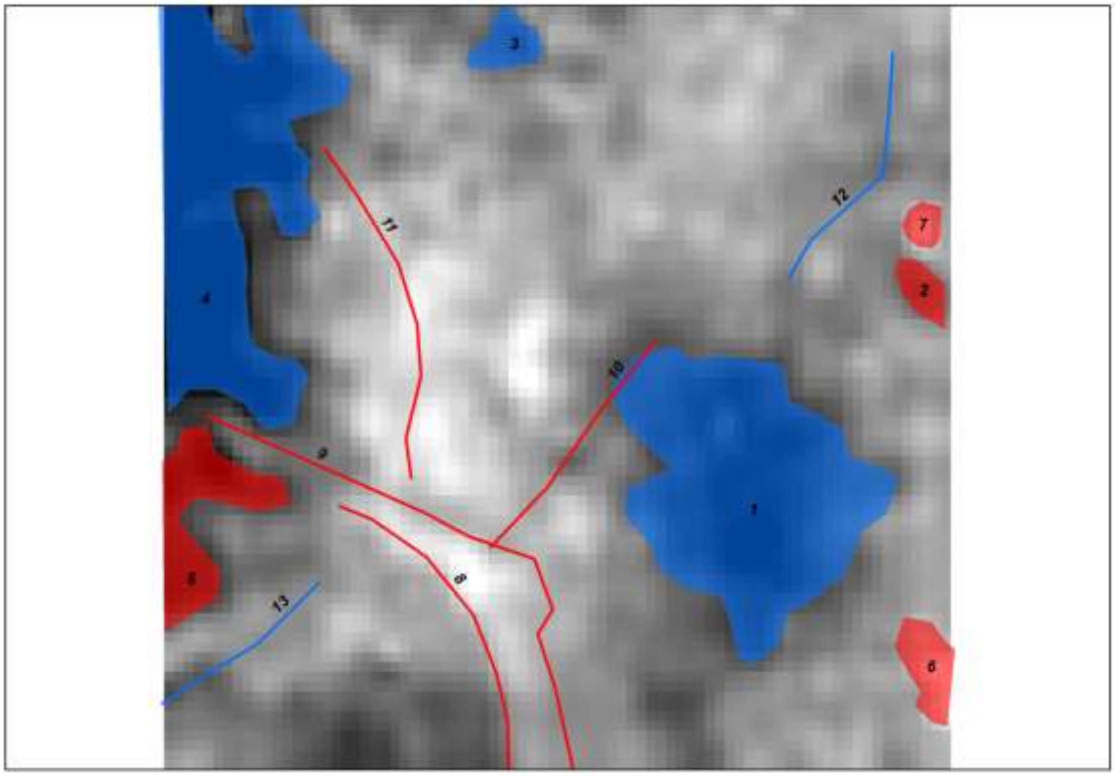
Earth Resistance



Id	Feature
1	Yes
2	Yes
3	No
4	No
5	No
6	Yes
7	No
8	No
9	Yes
10	No

(a) Final Count of all anomalies = __10_______
(b) Final Count of cultural feature anomalies = ___4________
(c) Final count of non-feature anomalies = _____6________

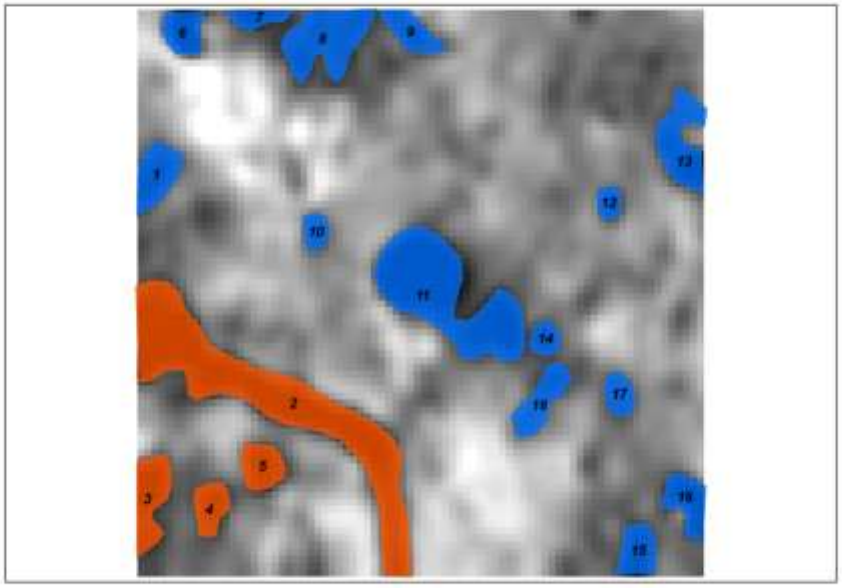
Conductivity:



Number	Feature
1	No
2	Yes
3	No
4	No
5	Yes
6	Yes
7	Yes
8	Yes
9	Yes
10	Yes
11	Yes
12	No
13	No

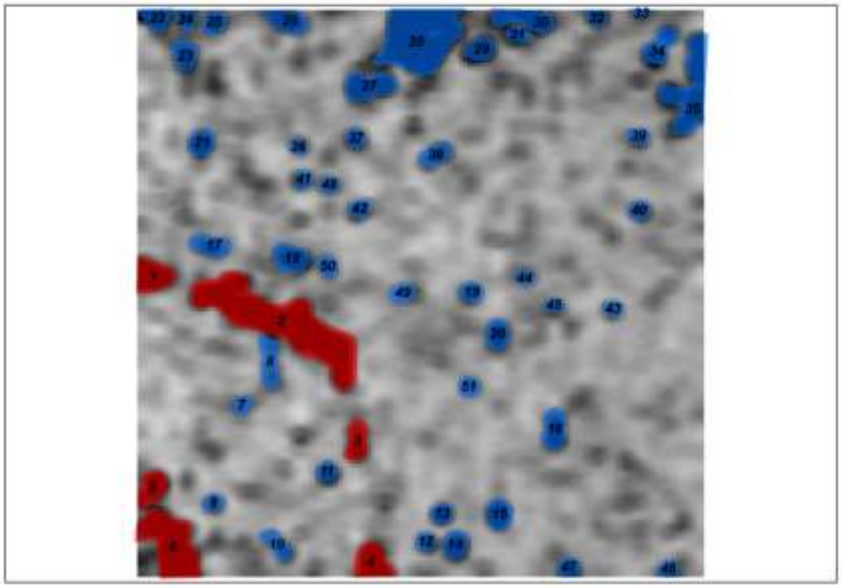
(a) Final Count of all anomalies = ____13_____
(b) Final Count of cultural feature anomalies = _____8______
(c) Final count of non-feature anomalies = _______5_____

Magnetic Susceptibility



Number	Feature
2	Yes
3	yes
4	Yes
5	Yes
1	No
6	No
7	No
8	No
9	No
10	No
11	No
12	No
13	No
14	No
15	No
16	No
17	No
18	No

(a) Final Count of all anomalies = ____18____
(b) Final Count of cultural feature anomalies = ____4_____
(c) Final count of non-feature anomalies = _____14______



Number	Feature
1	Yes
2	Yes
3	Yes
4	Yes
5	Yes
6	Yes
7	No
8	No
9	No
10	No
11	No
12	No
13	No
14	No
15	No
16	No
17	No
18	No
19	No
20	No
21	No
22	No
23	No
24	No

25	No
26	No
27	No
28	No
29	No
30	No
31	No
32	No
33	No
34	No
35	No
36	No
37	No
38	No
39	No
40	No
41	No
42	No
43	No
44	No
45	No
46	No
47	No
48	No
49	No
50	No
51	No

(a) Final Count of all anomalies = __51_______
(b) Final Count of cultural feature anomalies = ___6________
(c) Final count of non-feature anomalies = _____45________

8) Using *ArchaeoFusion*, examine each anomaly previously identified and report whether the anomaly occurs in other datasets, and if so which ones. A table such as the following is suggested (one for each datasets). The "total" column gives the total number of other datasets in which the same or similar anomaly was found.

You can copy, modify and expand this table using table tools in word, or use another program and paste here or include as a separate file.

Magnetometer Anomalies

Anomaly #	feature?	in Res?	in MS?	in Cond?	in GPR	total
1	Yes		x	x	x	3
2	No					0
3	Yes					0
4	No			x		1
5	Yes	x		x	x	3
6	Yes	x				1
7	Yes	x				1
8	Yes	x				1
9	No	x				1
10	Yes	x	x	x	x	4
11	No	x		x	x	3
12	Yes					0
13	Yes	x	x			2
14	Yes		x			1
15	Yes		x	x		2
16	Yes	x	x	x	x	4
17	Yes	x	x			2
18	No				x	1
19	No	x			x	2
20	Yes		x	x		2
21	Yes	x	x		x	3
22	Yes	x	x	x	x	4
23	No					0
24	Yes					0
25	No				x	1
26	Yes				x	1
27	No					0
28	No				x	1
29	Yes		x			1
30	Yes					0
31	Yes					0
32	Yes				x	1
33	No	x		x	x	3
34	No					0
35	Yes					0
36	Yes		x			0
37	Yes			x		1
38	No		x			1
39	Yes					0

Earth Resistance Anomalies						
Anomaly #	feature?	In Mag?	in MS?	in Cond?	in GPR	total
1	Yes	X	x		x	3
2	Yes					0
3	No					0
4	No	x				1
5	No					0
6	Yes	x		x		2
7	No	x				1
8	No	x	x	x		3
9	Yes	x	x			2
10	No			x		1

Conductivity Anomalies

Anomaly #	feature?	in Res?	in MS?	in Mag?	in GPR	total
1	No					0
2	Yes	x		x		2
3	No			x	x	2
4	No	x				1
5	Yes	x				1
6	Yes	x	x	x		3
7	Yes		x			1
8	Yes	x	x	x		3
9	Yes				x	1
10	Yes					0
11	Yes					0
12	No	x				1
13	No					0

MagSus Anomalies

Anomaly #	feature?	in Res?	in Mag?	in Cond?	in GPR	total
1	Yes		x			1
2	yes		x	x	x	3
3	Yes		x		x	2
4	Yes		x			1
5	No					0
6	No		x		x	2
7	No		x			1
8	No		x			1
9	No		x	x	x	3

10	No		x			1
11	No	x	x	x	x	4
12	No					0
13	No			x	x	2
14	No					0
15	No					0
16	No		x	x		2
17	No		x	x		2
18	No					0

GPR Anomalies

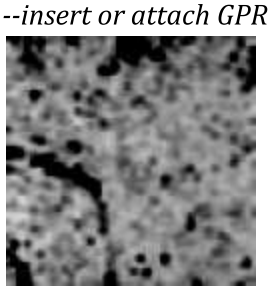
Anomaly #	feature?	in Res?	in MS?	in Cond?	in Mag?	total
1	Yes					0
2	Yes					0
3	Yes		x		x	2
4	Yes		x		x	2
5	Yes		x		x	2
6	Yes					0
7	No					0
8	No				x	1
9	No		x			1
10	No					0
11	No				x	1
12	No					0
13	No					0
14	No					0
15	No					0
16	No					0
17	No					0
18	No				x	1
19	No					0
20	No				x	1
21	No					0
22	No					0
23	No		x		x	2
24	No		x			1
25	No				x	1
26	No					0
27	No					0
28	No					0
29	No				x	1
30	No				x	1

31	No			0
32	No			0
33	No			0
34	No			0
35	No			0
36	No			0
37	No			0
38	No			0
39	No			0
40	No			0
41	No			0
42	No			0
43	No			0
44	No			0
45	No			0
46	No			0
47	No			0
48	No			0
49	No	x	x	2
50	No			0
51	No			0

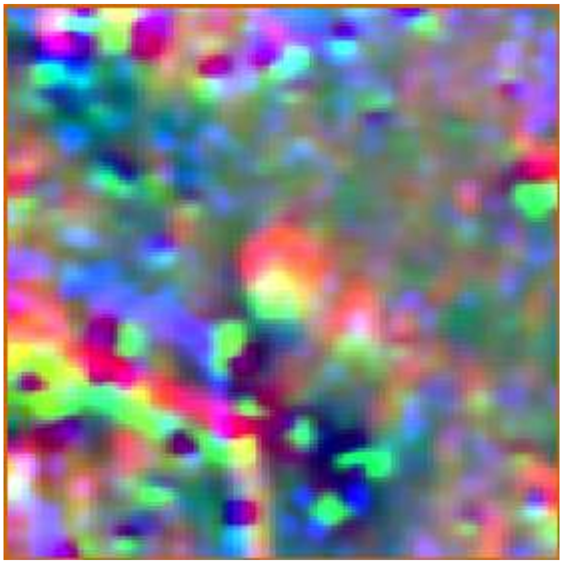
Part II: Objectives 2-3. The case for Data Integration

7) Use *ArchaeoFusion* to integrate or fuse some of the Los Adaes datasets and save the results as images (you will learn to use PCA, the Band Calculator, and transparencies).

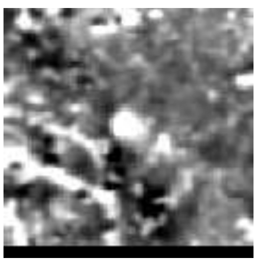
--insert or attach GPR PCA result—



--insert or attach screen capture (print screen) of translucent overlay result –



--insert or attach mathematical fusion using band calculator (sum3-5) –



8) Answer two multiple choice questions about your experience.

Please answer the following two multiple choice questions with reference to your experience from the exercises above (PCA of GPR slices, translucent overlays, and mathematical sum).

1) Integrating multiple datasets using ArchaeoMapper increased my ability to detect feature anomalies.

a Very true
b Somewhat true
c Neither true nor false
d Somewhat false
e Very false

2) Integrating multiple datasets using ArchaeoMapper increased my ability to determine one or more characteristics of the feature anomalies (e.g., feature size, shape, depth, relative location to other anomalies, whether it was burned, presence of rock concentrations, etc.).

a Very true

b *Somewhat true*
c *Neither true nor false*
d *Somewhat false*
e *Very false*

Part III: Objectives 5 & 7: The case for *ArchaeoFusion*

19) Time required to process and integrate at least two of the Los Adaes datasets in your software of choice (whatever you normally use, but not *ArchaeoFusion*). If you have experience with GPR and/or EM then we need you to choose these since this is the biggest strength of *ArchaeoFusion*. If you are only familiar with one method then that is ok, but try to use a second if you can. It would be best to get a detailed time log from you for each step of the way – e. g. how long it took to import and assemble the EM data, then to process it, then to preprocess the GPR data, slice it, assemble slices, process them, then integrate both together. If you do not know how to integrate multiple datasets then just state that this part could not be completed given your experience or limits to software.

    --insert a summary of how much time it took you to process and integrate each chosen dataset--

20) Instructions for another person to replicate what you did. Think of this as creating an archive, which should contain raw data, finished results and a description of how the results were achieved. It is up to you how you want to do this. You might decide that you want to avoid being software-specific, or you could provide directions requiring a certain software. This is one of the challenges of creating a data archive. This can also be time consuming and so you should be realistic about how much detail you are able to provide given your time constraints. It could range from a copy of hand-written notes to a more formally written document. If your archive does not contain all of the details required for someone else to reproduce what you did then this is simply a reality and helps identify where geophysics software needs improvement.

    --insert or attach instructions and also email them to Eileen at eernenw@cast.uark.edu as soon as possible—

21) Time required for you to replicate another person's results by following their directions (please complete the other deliverables and you will be notified when there are instructions from someone else for this part.)

    --insert a summary of how much time it took you to process and integrate each chosen dataset following someone else's instructions and using your software of choice--

22) Time required for you to process and integrate the provided Los Adaes datasets using *ArchaeoFusion*. Again, try to provide a detailed time log like the one for your work in other software. Step-by-step instructions for this are provided below.

--insert a summary of how much time it took you to process and integrate each chosen dataset--

23) Instructions for another person to replicate what you did using *ArchaeoFusion*. Just as for #2 above, think of this as an archive with raw data, final results, and a description of how the results were achieved. This could look something like what is provided for you in the instructions. *ArchaeoFusion* will eventually have an export function for creating an archive (will include raw data, results, and all processing steps), but it will not be ready for the first version. In the mean time, you can get data processing information for each survey by opening the "survey.operationlist" file in WordPad. This file is located in the project folder under surveys, and then the name of the survey. For example, for the res data used in the first project the file is here: LosAdaesProjectN610E470\Surveys\res\survey.operationlist. You can also save the operation stack and include it in the archive.

--insert or attach instructions and also email them to Eileen at eernenw@cast.uark.edu—

24) Time required for you to replicate another person's results by following their directions and using *ArchaeoFusion* (again, you will be notified when directions are ready for you. First complete the other deliverables and submit them, so your instructions can be used by another participant).
*deliverables 3 and 6 cannot be done until we get deliverables 2 and 5 from other participants and send to you. Please complete 1, 2, 4, and 5 and send to us as soon as you can so we can send them to other participants to complete 3 and 6.

--insert a summary of how much time it took you to process and integrate each chosen dataset following someone else's instructions and using ArchaeoFusion--

APPENDIX F: ASSESSMENT 2 ONLINE SURVEY

ArchaeoFusion Users Survey
(hosted online at http://www.surveymonkey.com/s/S5YL22D)

INSTRUCTIONS: Please indicate your level of agreement with the following statements.

1. In regards to archaeological geophysics in general (regardless of software): multiple surveys, even when not integrated, provide more useful information than single sensor surveys.

Strongly Disagree Disagree Neutral Agree Strongly Agree

2. In regards to archaeological geophysics in general (regardless of software), data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc) increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets.

Strongly Disagree Disagree Neutral Agree Strongly Agree

3. *ArchaeoFusion* allows users to effectively integrate data from multiple sensors (i.e. overlays, translucent overlays, band calculator, principle components analysis, and k-means cluster analysis).

Strongly Disagree Disagree Neutral Agree Strongly Agree

4. Data from all major sensor types can be adequately processed using *ArchaeoFusion* alone.

Strongly Disagree Disagree Neutral Agree Strongly Agree

5. In comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers (i.e. GPR, EMI, magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. (metadata is the information about your data, such as what instrument was used to collect it, the start corner and direction for the survey, etc.).

Strongly Disagree Disagree Neutral Agree Strongly Agree

6. *ArchaeoFusion* preserves data resolution. (meaning, that when you are finished processing your data, you can always revert to the original data with the original data density).

Strongly Disagree Disagree Neutral Agree Strongly Agree

7. Data processing using *ArchaeoFusion* is faster and easier than processing using other COTS (commercial off-the-shelf) software.

Strongly Disagree Disagree Neutral Agree Strongly Agree

8. Ground-truthing (test excavations to evaluate interpretation of geophysical data) enhances the usefulness of geophysical data.

Strongly Disagree Disagree Neutral Agree Strongly Agree

9. Please comment on the benefits of *ArchaeoFusion* and describe any shortcomings that you perceive.

APPENDIX G: *ARCHAEOFUSION* BETA TEST PARTICIPANTS

Army Users Group Participants

Participant #	Position	Instrument Experience	Software Experience	Years of Experience
1	Cultural Resources Manager, Fort Drum	Magnetometry – Geoscan FM36 gradiometer, Geoscan RM15 resistance meter, GSSI SIR 20 Radar	ArcMap 9.2, Surfer	4 years (intermediate experience level)
2	Cultural Resources Manager, Fort Riley	Geoscan FM36 Gradiometer, Geoscan RM15 Resistance Meter	Geoplot, Surfer	8 years (intermediate experience level)
3	National Park Service	Magnetometry, resistance, resistivity, EM, GPR, magnetic susceptibility, digital compaction, metal detection. Magnetics: Geometrics, GEM, Geoscan, Bartington; resistance: Geoscan; resistivity: Geohm; EM: Geonics EM31,38,61; GPR: GSSI, Sensors and Software, MALA; magnetic susceptibility: Bartington; digital compaction: Spectrum Technologies	Geoplot ArchaeoSurveyor Geosoft Surfer, Grapher, MagMapper, Geonics DATW for EM-31, -38, -61 Bartington, Magnetic Suscept.	14 years (highly experienced)
4	U.S. Forest Service (retired)	EM31, GEM300. Specializes now in GPR, GSSI primary data collector but processes mala SS	Surfer, Easy Cad Dat31w, Slicer Dicer Radan, GPR-Slice, ArcView, Photoshop, MS Excel	30 years, (highly experienced)

University of Arkansas Student Participants

Participant #	Position	Instrument Experience	Software Experience	Years of Experience
5	Anthropology PhD Student	Magnetometry, Resistivity, EM, GPR Geoscan (RM15, FM256), Bartington, GSSI (2000, 3000), EM38B, TRI/CARES	Geoplot, ArchaeoSurveyor	4 years
6	Anthropology PhD Student	Geoscan, Magnetometry and Resistivity	Geoplot ArchaeoSurveyor	4 years
7	Anthropology Masters Student	GPR (GSSI SIR 2000), EM (EM_38), Magnetic Gradiometry (FM256, Bartington 601.), Resistance Meter (RM-15/MXP 15 and TR Systems CIA)	GPR Process ArchaeoSurveyor	2 years
8	Anthropology Masters Student	Bartington, GSSI (GPR), Gisco (conductivity), Magnetic Susceptibility, Resistivity	Surfer ArcGIS	<1 year

APPENDIX H: *ARCHAEOFUSION* BETA TEST RESULTS

Rating Summaries and Selected Comments

In general, all the participants were pleased with the usability, functionality and effectiveness of ArchaeoMapper (now called *ArchaeoFusion*). Numerical ratings are summarized for each tutorial in the tables below.

Tutorial 1: Basics

Tutorial 1 was broken into two parts for scoring purposes. The first part of the tutorial included parts I-V. The second parts VI-VIII. The scores for both parts of the tutorial are summarized in the table below and separated by slashes. NR indicates that no rating was provided by that user.

	BTP1	BTP2	BTP3	BTP4	BTP5	BTP6	BTP7	BTP8
Ease of Use	4/NR	4/4	NR/NR	4/4	4/NR	4/NR	4/5	
Accuracy	4/NR	5/5	NR/NR	4/4	4/NR	4/NR	5/5	
Effectiveness	4/NR	4/5	NR/NR	4/4	4/NR	4/NR	5/4	

Table 1a. Numerical Ratings, Tutorial 1.

Beta Test Participant 2	"Most of the specific comments were addressed by the people coordinating the beta test. I do like some of the features from the survey editor such as the brightness and contrast bars better than I do those same features in the actual ArchaeoMapper interface. There are at least a couple of tools that seem like they would be very useful in the ArchaeoMapper data processing interface. Specifically the grid drawing tool, and the ability to alter the size of the grid. A measuring tool might also be nice to determine intra- and inter-feature dimensions. Also having the gridding and measuring functions could facilitate producing plans for ground truthing or feature testing. As a final thought the software seems very user friendly. After today I feel capable of navigating the functions we beta tested. Kudos to the designers and programmers!!!!"
Beta Test Participant 1	"I was able to navigate through the tool bars and for the most part able to make the software do what I wanted it to do. I also am not very good at new software, so if I am able to navigate, it must be pretty easy to use."
Beta Test Participant 4	"Got comfortable with this phase of software fairly quickly." "functions well with good results" "makes easier to use multiple datasets"

Table 1b. Comments, Tutorial 1.

Tutorial 2: Updating surveys with new data, and loading EM (magnetic susceptibility and conductivity) and 2D GPR slices into ArchaeoMapper.

Tutorial 2 was broken into three parts for scoring purposes. The first part of the tutorial included Parts I-III, the second Parts IV-V and the third Parts VI-VIII.

	BTP1	BTP2	BTP3	BTP4	BTP5	BTP6	BTP7	BTP8
Ease of Use	4/3/4	4/NR/NR	4/4/4	3/2/2	4/NR/NR	NR	NR	NR
Accuracy	4/4/4	5/NR/NR	4/3/4	3/2/2	4/NR/NR	NR	NR	NR
Effectiveness	4/4/4	5/NR/NR	4/3/4	3/2/2	5/NR/NR	NR	NR	NR

Table 2a. Numerical Ratings, Tutorial 2.

BTP3	"After working with the software yesterday, it was much easier to use it today."
BTP1	I was able to navigate through the tool bars and for the most part able to make the software do what I wanted it to do. I also am not very good at new software, so if I am able to navigate, it must be pretty easy to use.

Table 2b. Comments, Tutorial 2.

Tutorial 3: GPR Processing and data fusion.

Tutorial 3 (which does not have written instructions) was an instructor-led tutorial that covered data fusion and GPR processing and slicing.

	BTP1	BTP2	BTP3	BTP4	BTP5	BTP6	BTP7	BTP8
Ease of Use	NR	3	NR	NR	NR	NR	NR	NR
Accuracy	NR	5	NR	NR	NR	NR	NR	NR
Effectiveness	NR	5	NR	NR	NR	NR	NR	NR

Table 3a. Numerical Ratings, Tutorial 3.

Tutorial 3 was a demonstration of data fusion techniques and the *ArchaeoFusion* approach to GPR processing. Although the participants had tasks to complete, they were guided by the development team via the instructor's podium and overhead projector. This, and the fact that the tutorial took place at end of Day 3 (the beta test's final day), account for the lack of user ratings for this tutorial. However, the Overall Assessment does provide some commentary on this functionality and participant comments are addressed in the *ArchaeoFusion* modification list below.

Overall Assessments Results

Results from the Overall Assessment are summarized below.

We are very interested in your assessment of the current status of the ArchaeoMapper software and its potential to improve the use of geophysics in archaeology, specifically archeological investigations at DoD facilities but also more broadly applied. We have previously asked for

your comments on each part of the software and ways to improve it. Now we want your overall assessments.

Note: In the following we are using the term "archaeological studies" to apply typically to **evaluation and mitigation level efforts** and in those conditions where geophysics is a feasible method.

Summarized answers include the four (4) Army Test Group participants.

We would like to get your assessment of some general issues first.

1) Geophysical investigations as part of archaeological studies …
   a) are currently adequate
   b) are currently excessive
   c) are currently inadequate (4)

2) Appropriate levels of geophysical investigations as part of archaeological studies …
   a) Usually reduce costs and save time (3)
   b) Usually add costs and time (1)
   c) Will not change the current total costs or time

3) Without considering cost or time, geophysical investigations, when made part of archaeological studies …
   a) Commonly improve the quality of the archaeological results (4)
   b) Commonly do not improve the quality of the archaeological results
   c) Commonly have little effect on the quality of the archaeological results

4) In the next 10 years …
   a) Geophysical investigations in the US will come to be a required part of most archaeological studies - as they are now in England – by SHPOs and other review groups (1)
   b) Most archaeological studies in the US will not involve geophysics even when conditions are appropriate for their application
   c) Geophysical investigations in the US will come to be a recommended but not required part of most archaeological studies by SHPOs and other review groups (3)

This ESTCP project has two objectives:

1) Assemble a single, user-friendly software that will serve as an effective medium for infusing the integrated, multi-sensor geophysical approach into wide use.

2) Demonstrate and validate the cost and performance benefits of the approach and technology infusion tool to DoD geophysical users, representatives of federal, state, and other CRM practitioners, federal and state resource managers.

In the following we are interested in your assessment of ArchaeoMapper's ***potential*** to meet objective 1 in the ESTCP proposal. In these questions we want your assessment of ArchaeoMapper for …

(i) a person new to the use of geophysics in archaeology

(ii) a user that is generally knowledgeable about geophysics but is not an "expert" and

(iii) an expert user with lots of experience in archaeological geophysics.

Note: If you feel you are unable to answer from one or more of these perspectives just leave the question(s) blank.

From the perspective of a new user please agree or disagree with the following:

5) The ArchaeoMapper interface provides a good geophysics "road map" for the new archaeological user
   a) Strongly agree (2)
   b) Agree
   c) Neutral (1)
   d) Disagree
   e) Strongly disagree

6) The ArchaeoMapper interface is easy-to-use for a new user
   a) Strongly agree (1)
   b) Agree (3)
   c) Neutral
   d) Disagree
   e) Strongly disagree

7) There is valuable flexibility in the user interface and the structured analysis approach for the new user
   a) Strongly agree (1)
   b) Agree (3)
   c) Neutral
   d) Disagree
   e) Strongly disagree

8) Because ArchaeoMapper is easy-to-learn and easy-to-use (as compared to others) we will likely see an increase in the use of geophysics in archaeological investigations
   a) Strongly agree

b) Agree (3)
c) Neutral (1)
d) Disagree
e) Strongly disagree

From the perspective of an intermediate user:

9) ArchaeoMapper combines ease-of-use with valuable flexibility for my applications
   a) Strongly agree (4)
   b) Agree
   c) Neutral
   d) Disagree
   e) Strongly disagree

10) ArchaeoMapper provides me with most of the tools I expect to use in my geophysical applications
   a) Strongly agree (3)
   b) Agree (1)
   c) Neutral
   d) Disagree
   e) Strongly disagree

11) ArchaeoMapper will reduce the **time** I need to process my data
   a) Strongly agree (2)
   b) Agree (2)
   c) Neutral
   d) Disagree
   e) Strongly disagree

12) ArchaeoMapper will reduce the **cost** to process my data
   a) Strongly agree (1)
   b) Agree (2)
   c) Neutral (1)
   d) Disagree
   e) Strongly disagree

13) By combining the ability to ingest raw data from many different instruments, process it and fuse the results I will be able to obtain more effective results than I have before reducing overall project costs and or time
   a) Strongly agree

b) Agree (3)
c) Neutral (1)
d) Disagree
e) Strongly disagree

14) The availability of ArchaeoMapper will increase the use of geophysics in archaeological investigations
a) Strongly agree (4)
b) Agree
c) Neutral
d) Disagree
e) Strongly disagree

From the perspective of an **expert** user

15) ArchaeoMapper combines ease-of-use with flexibility for my applications
a) Strongly agree (1)
b) Agree (1)
c) Neutral (1)
d) Disagree
e) Strongly disagree

16) ArchaeoMapper provides me with most of the tools I expect to use in my geophysical applications
a) Strongly agree (1)
b) Agree (2)
c) Neutral
d) Disagree
e) Strongly disagree

17) ArchaeoMapper will reduce the **time** I need to process my data
a) Strongly agree
b) Agree (2)
c) Neutral (1)
d) Disagree
e) Strongly disagree

18) ArchaeoMapper will reduce the **costs** I incur to process my data

a) Strongly agree
b) Agree (2)
c) Neutral (1)
d) Disagree
e) Strongly disagree

19) The availability of ArchaeoMapper will increase the use of geophysics in archaeological investigations
a) Strongly agree
b) Agree (1)
c) Neutral (2)
d) Disagree
e) Strongly disagree

20) By combining the ability to ingest raw data from many different instruments, process it and fuse the results I will be able to obtain more effective results than I have before
a) Strongly agree (2)
b) Agree (1)
c) Neutral
d) Disagree
e) Strongly disagree

Software Modifications

Immediately after the beta test (Nov 7, 2008) and again approximately two weeks after the test (Nov 20, 2008) the ArchaeoMapper software development team met to review and discuss the participants' comments from Tutorials 1-3 and the Overall Assessment Questionnaire. The results of these two formal review periods and other informal discussions is the following categorized and prioritized list of modifications to ArchaeoMapper to be made as soon as possible and before submission of the Field Demonstration Plan. Items in red indicate "bugs", items in black are considered improvements and feature additions. Items in blue have been addressed since the beta test. Many of the modifications listed below may be unclear to someone unfamiliar with the ArchaeoMapper software. However, all of them have been reviewed by the development team.

<u>ArchaeoMapper Data Viewer and Processing Interface</u>

1. Retain and operate on original data values in all surveys. Provide tools to adjust mapping of those values to 0-1 for display (std, contrast, etc). Also provide a button to enable dynamic range adjustment so that after an operation is run, a preset mapping is applied to

the display (e.g. 2 std and gamma 1). This would almost eliminate the need for the stretch operation (although it should be retained).

2. Gray out "Edit Survey" or "Add Survey" until a project is created.
3. Templates are saved in C:\Program Files\ArchaeoMapper but non-administrator accounts can't write to that folder. Make write privileges part of install.
4. Remove 1 x 1 options in filter size or modify Matlab function that gets passed a 1x1 filter.
5. Specify window size in meters and build filter based on sample rates from each individual tiles.
6. When a project is saved, need "some clear indication that it was actually saved."
7. In Save Project dialogue, "location" is misspelled (missing the "i")
8. On initial import, layer is checked, but not visible. Un-checking and re-checking shows layer.
9. When layer order is changed, the display is not refreshed.
10. Use a file as en entry point to a project instead of a folder. Enable double-click on the project file to open the project in AM.
11. Range Match: add a new interface to choose which tile to match too. Perhaps the N, S, E, W arrow layout. Do not allow "All" selection. Allow area selections and match against adjacent samples in the same tile.
12. Enable meta-data display for surveys. Right-click maybe. Should at least show sample rates and traverse pattern/direction.
13. Operations should close automatically after run.
14. When an existing project is loaded, the entire operation stack should not have to be re-run from the beginning.
15. When parameters of operations change, the user should be notified that the stack is not current. That is, what they see on the display does not represent the current stack. Perhaps a red light - green light near the Run Operation Stack button as an indicator. Also, perhaps changing the color of the operation button (soft yellow) to show that it has changed.
16. Clicking the "I" button of an inactive operation shows the result stored on disk. This is not intuitive since the user thinks that process is inactive. The "I" and "H" buttons should be grayed-out if the operation is inactive. There seem to several issues related to the operation stack in which the order of saved operations is confused.
17. If an operation is unchecked, gray it out to make it more obvious to the user that it has been skipped over when the operation stack was last run.
18. Remove the need for a No-Op.
19. Toggle button to show grid lines with a specified spacing.
20. Toggle button to show tile boundaries
21. Histogram windows are often hidden behind each other and behind the main AM window.
22. Move display controls to Split Pane on the right. Move histogram to this pane.
23. Add ability to change color of shards.
24. Load GeoTiff, DEM (one format only).
25. Zoom to Survey needs to adjust eye point and reorient to North is Up. Center of screen needs to be centroid of survey, not origin.
26. Right hand screen Smooth button shows tile boundaries.
27. Colormaps do not have enough entries, need 256x3 colormap.
28. Add more colormaps. Particularly have one that is reverse grayscale, but with all values beyond min/max displayed as blue/red.

29. Allow colormaps to be reversed
30. New surveys should be added to an existing shard if possible. Even number of active shards do not allow for highlighting.
31. Band calculator: add Boolean logic, power, square, max and min functions to calculator. Min and max will take the max data value of multiple bands in a given location. Syntax might be max(B1,B2,B3) or min(B1,B5).
32. Band calculator: A false expression such as "6B195" returns a result.
33. Adjust exaggeration of height map.
34. When a recently fused survey is opened in the Survey Editor, it displays with no data values (gray, black, maybe). The originating survey is unaffected. This is due to the lack of a mapping from data values to 0-1.
35. 1D Fourier and 2D Fourier can easily cause catastrophic crash of AM. Need to make the viewer inactive while user is working in the filter window, and make sure the filter window is closed to bring user back to viewer (?)
36. Rename Fuse Surveys Tool -> doesn't make sense when breaking apart surveys.
37. Add options to Fuse Survey Tool such as an option to retain tile information or merge into a single "image". Perhaps a resample option.
38. Rename Band_0, Band_1, etc somehow? based on the measurement type from the file header. If a name doesn't exist, then use B1, B2, etc to be consistent with the Band Calculator. Layer/survey entries should be show band labels (B1, B2, etc).
39. It is hard to tell if Band buttons (B1, B2, etc) are depressed or not.
40. Export survey to SURFER grid format.
41. Digitize points (lat/lon) in survey for export to text file and possibly as GPS waypoint file. This is also a way to output locations of anomalies for planning excavations.
42. Export to KML for quick sharing and review.
43. Layout view with ability to add north arrow and scale bar.
44. Compile all Matlab functions as a Java Package (need Java Builder for Matlab).
45. Organize toolbar. Add tool-tips with full operation name and short description
46. GPS import. How to do this? via interpolation?
47. Measuring tool
48. Difference button - make it so that it shows the difference between two places in the operation stack that the user selects. Or at least make it so it shows the difference for the last operation done, not the last in the stack.
49. Difference button - Make it so that it does not disappear when mouse is not close, and so you can tell that it is on or off.
50. Add buttons to toolbar for creating a new survey or editing a survey.
51. Allow selection of multiple contiguous tiles using a box rather than clicking each one individually.
52. Add labels to the values displayed for pixels when you click in the viewer.
53. Allow user to add a previously created survey to the current project.
54. Toggle button to show tile labels in the viewer and survey tool.
55. Add a log file to show everything the user has done.

Survey Tool/Tile Editor

1. Need to add "feet" vs. "meter" choice to Survey Tool.

2. Add “Auto Assemble” tiles if X, Y values represent survey coordinates.
3. Change initial snap size to 2m in Survey Editor.
4. When snap size is changed, the blue grid does not change. The show grid button must be un-clicked and clicked.
5. Add ability to select/shift/move multiple tiles in Survey Tool.
6. In Survey Editor, may the origin more obvious. Brighten yellow lines, add text, datum mark, etc.
7. Survey tool crashes on Tile Rotate.
8. Tile Editor Undo causes catastrophic crash of AM.
9. Survey Editor navigation control should be similar to Survey Viewer.
10. Some data sets (EM, maybe others) come in to viewer reversed (min data value is mapped to 0, not 1).
11. Add ability to toggle tile name display in the Survey Editor and the Survey Viewer.
12. Standardize slice names to reflect depth range.
13. In the tile editor tool, lines shifted to the left loose forever values shifted off the tile. This can't be repaired with subsequent shifts to the right.
14. GPR Slicing: Down-sample when creating slices and give participants options for how to do this: nearest neighbor, averaging, etc. A good default would be 8 pixels per meter in the traverse direction, using pixel aggregation or averaging (to avoid smoothing).
15. Tile Editor "reset" button. Add text to tell the user that this will put the origin in the lower-left corner.
16. Tile Editor: Need a clearer indication that the tile is selected when you are going to alter the size, etc. Currently a blue box is drawn, but then it disappears when you move your mouse to the "Alter tile" button.
17. Tile Editor: Rather than "none" button, use a black arrow or something more intuitive.
18. Tile Editor: When you open the survey tool to create a new survey, it should open with the default values, not the previous settings - especially the survey name.
19. Load Tile dialogue box: once you select a template - you cannot unselect it (?)
20. Icons for rotating and flipping (mirroring) tiles are not clear. Add pop-up text?
21. Survey Tool: There needs to be some indication that a tile has been rotated or flipped.
22. Adding tiles: “When you first enter the add tiles window it prompts you to enter the parameters and hit ‘next’ on a couple of screens. After the second next it prompts you to save your template. As soon as you hit save it opens a windows-based explorer pop-up. The system expects you to select tiles to use to populate your template, but in the sequence of events that leads to this window it seems like you should be searching for somewhere to save your template. I found this confusing. It seems that there ought to be some sort of prompt to search for raw data prior to the windows explorer pop-up.”
23. Survey Tool: For changing the tile size in the survey tool: In tutorial #2 the GPR surfer grids were slightly smaller than they were supposed to be, so we had to resize. The size as listed in those boxes had several decimal places, and the number were displayed so that you could not see the number from the left (you could only see the last few digits on the right). So you have to put your cursor in each box and use the back arrow key to see the original number. So these numbers need to load so they are left-justified, and probably with fewer decimal places.

GPR Wizard

1. GPR should be able to handle perpendicular tiles, but not in tiles.
2. Should we try to handle GPR obstacles?
3. Incorporate topographic correction.
4. GPR Wizard: out of memory problem (will be solved with Java/Matlab interaction change).
5. GPR Wizard: window too large if profiles are long (will add scroll bar to window)
6. GPR Wizard: ways to rearrange profiles other than little arrows
7. GPR Wizard: show individual traces rather than mean trace when gaining
8. GPR Wizard: Annotate velocity curve points with depth, time, velocity, and relative dielectric permittivity.
9. GPR Wizard: slice thickness slider bars should have a scale in ns and meters, not just samples 0-511.
10. GPR Wizard: Vertical filter
11. GPR Wizard: Gaining step(s) could be eliminated until the last step if display gains are added so the use can adjust gains as needed while going through each step.
12. GPR Wizard: for distance normalization between marks, allow user to input number of traces per meter. Use pixel aggregation (averaging) rather than pixel thinning (resampling) if possible.
13. GPR Wizard: export 3D cube in generic formats for bringing into other programs.
14. GPR Wizard: Time zero correction should optionally operate on each trace, or the average trace per profile.

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APPENDIX K: 2009 AGENDA FOR THE NPS COURSE

(Compiled by Steve De Vore)

Current Archeological Prospection Advances
for Non-Destructive Investigations in the 21st Century

Monday, May 18

Morning (Lecture 8:00-12:00)	
Introduction (Steven De Vore)	0.50 hr
Geophysics and Archeology Introduction (Jarrod Burks, Jami Lockhart and Mike Hargrave)	1.50 hr
Aerial Photography Introduction (Tommy Hailey)	1.00 hr
Site Selection Criteria (Lew Somers)	0.50 hr
Metal Detectors (Steven De Vore)	0.50 hr
Lunch	1.00 hr
Afternoon (Field 1:00-5:00)	
Description and Preliminary Assessment of Cultural Resources At Los Adaes State Historic Site/Fort Jessup State Historic Site (George Avery, Pete Gregory, Mike Hargrave, Jamie Lockhart, & Tommy Hailey)	1.00 hr
Geophysical Equipment Demonstrations—All Instruments (Instructors)	3.00 hr
Evening (7:00-9:00 pm)	
Participant Introductions	1.50 hr
The Foerster FEREX Vertical Fluxgate Gradiometer for Geo-magnetic Survey – System Setup and Handling – Field Survey Results (Himmler and Myles)	0.50 hr

Tuesday, May 19

Morning (Lecture 8:00-12:00)	
Resistivity/Resistance Surveys (Doug Groom, Kris Lockyear, & Lew Somers)	1.00 hr
Total Field and Gradient Magnetic Surveys (Jarrod Burks, Jami Lockhart, & Lew Somers)	1.00 hr
Electromagnetic Conductivity (Rinita Dalan & Berle Clay)	1.00 hr
Magnetic Susceptibility (Rinita Dalan)	1.00 hr

Lunch	1.00 hr
Afternoon (Field 1:00-5:00)	
Field Use of Equipment at the Los Adaes/Fort Jessup State Historic Sites (Instructors)	4.00 hr
Evening (7:00-9:00 pm)	
Basic Magnetic, Resistance, and Conductivity Data Processing (Instructors)	2.00 hr

Wednesday, May 20

Morning (Lecture 8:00-12:00)	
Multi-instrument Surveys (Jarrod Burks, Mike Hargrave, & Berle Clay)	1.00 hr
Geophysical Data Processing (Lew Somers)	2.00 hr
Demonstrations of Magnetic, Resistance, Conductivity, and Magnetic Susceptibility Processing Software (Instructors)	1.00 hr
Lunch	1.00 hr
Afternoon (Field 1:00-5:00)	
Field Use of Equipment at the Los Adaes/Fort Jessup State Historic Sites (Instructors)	4.00 hr
Evening (7:00-9:00 pm)	
Basic Magnetic Susceptibility & Other Geophysical Data Processing (Instructors)	2:00 hrs

Thursday, May 21

Morning (8:00-12:00)	
Ground Penetrating Radar (Dan Welch, Larry Conyers, Sarah Lowry, & Greg Summers)	2.00 hr
Demonstration of ArchaeoFusion Geophysical Processing Software (Mike Hargrave)	***2.00 hr***
Lunch	1.00 hr
Afternoon (Field 1:00-5:00)	
Field Use of Equipment at the Los Adaes/Fort Jessup State Historic Sites (Instructors)	4.00 hr
Evening (7:00-9:00 pm)	
Ground Penetrating Radar Data Processing (Instructors)	2.00 hr

Friday, May 22

Morning (8:00-12:00)

Student Projects	1.00 hr
Demonstrations of Ground Penetrating Radar Processing Software (Instructors)	1.00 hr
Ground Truthing Geophysical Anomalies (Jarrod Burks & Mike Hargrave)	1.00 hr
Interpretation of Week's Field Work (Instructors)	1.00 hr
Course evaluations due at end of morning	

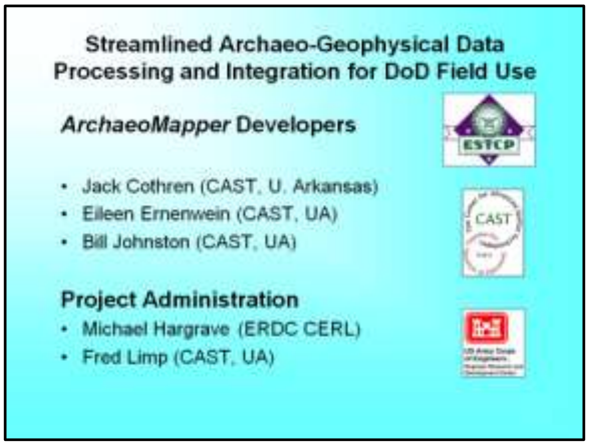
Lunch	1.00 hr

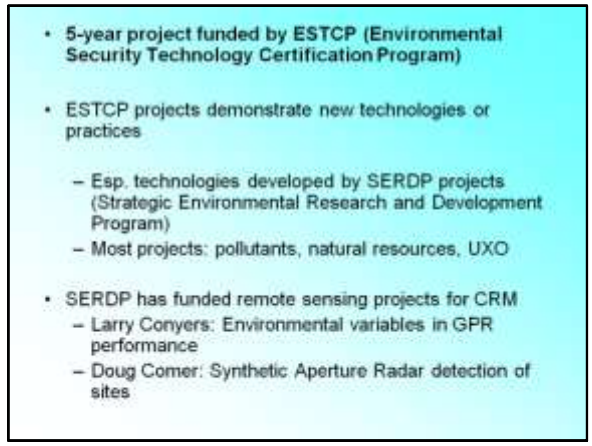
Afternoon (Field 1:00-5:00)

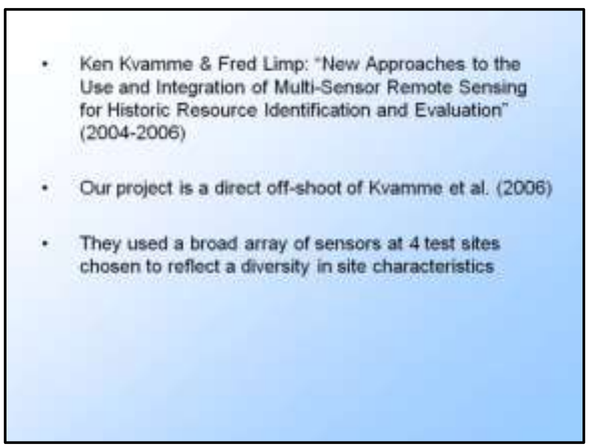
Field Use of Equipment at the Los Adaes/Fort Jessup State Historic Sites (Instructors)	4.00 hr

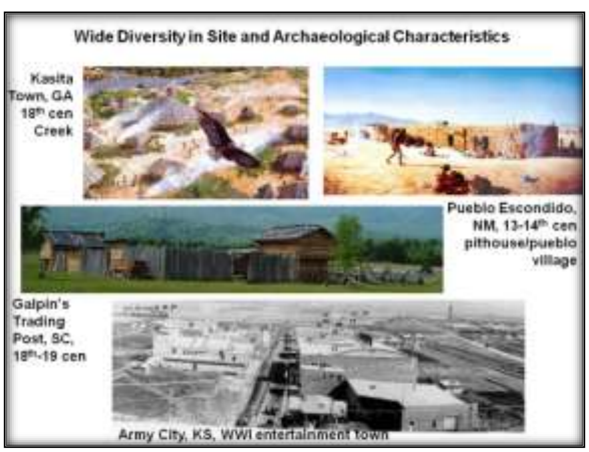
APPENDIX L: PROJECT OVERVIEW PRESENTED AT 2009 FIELD DEMONSTRATION

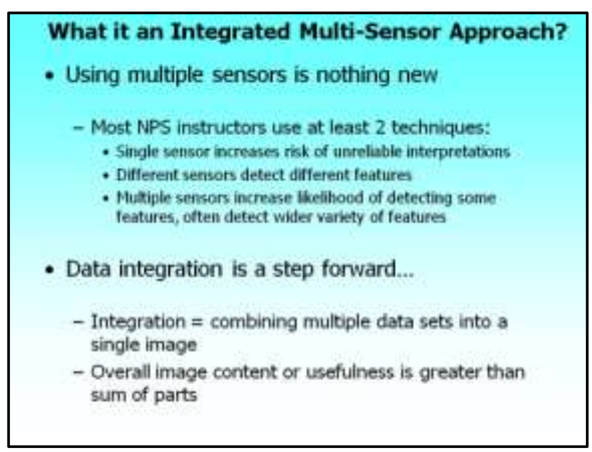
Slides proceed left to right, top to bottom.



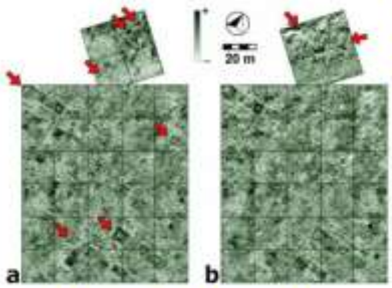








Different Sensor Types Provide Non-redundant Information



Structures seen at different depths in GPR slices

GPR slices:
a. 31-47 cm bs
b. 47-63 cm bs

GPR data from Pueblo Escondido

*Images courtesy Ernenwein and Kvamme

Goal is an image of all features seen in geophysical data

No single data set shows all features

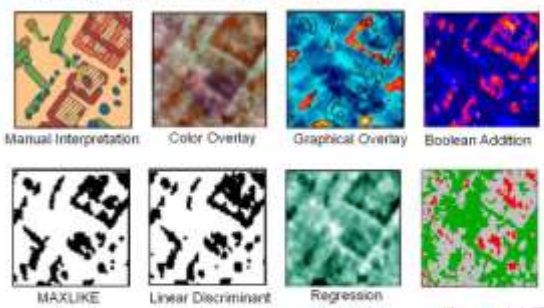
Vectorization is time consuming

Ideal would be to achieve this content in an integrated geophysical map

*Images courtesy Ernenwein and Kvamme

Kvamme and Ernenwein Investigated Many Ways to Integrate Multi-sensor Data

One 20 by 20-meter area at Pueblo Escondido:



*Kvamme et al. 2006

Types of Data Integration*

- Graphical overlays (e.g., contour lines atop image map)
- Color composites, translucent overlays
- Discrete methods (Boolean to cluster analyses)
- Simple math operations (sums or ratios)
- Multivariate (principal components to regression)
- Intelligent knowledge based approaches
- Expert systems

*Kvamme et al. 2006

Benefits of Data Integration

- Visualization of "all" geophysical expressions of subsurface deposits
- Images of anomalies not clear in any single dataset
- Which sensor detects an anomaly is informative about its character
- Some integrations can display high and low contrast anomalies together
- Image content is not the same as pleasing appearance
- On balance, integration will sometimes be useful, sometimes not

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Data Integration Currently Requires...

- Math and statistical expertise
  - Most of us lack it
- Knowledge of multiple software:
  - To download
  - To assemble and process data
  - Spread sheets to correct data
  - GIS to display
- Many hours of processing
- Repetition when additional data added
- Manual recording of meta-data
  - So many steps, one forgets what was done

Our Project Goals

R & D Component:

- Develop user-friendly software that can:
  - Down-load and process all major data types (no other software needed)
  - Meet processing needs of expert users
  - Guide less experienced users to acceptable results
  - Support data integration

Demonstration Component:

- Demonstrate all steps in the integrated multi-sensor approach
- Make IMS approach available to DoD CRM personnel (non-expert geophysical users)

Demonstration Component

- User Group evaluates *ArchaeoMapper*
  - (De Vore, Hall, Lockhart, Rush, Schneider)
  - Beta-test (November 2008)
  - Evaluate *ArchaeoMapper's* performance (2009)
  - Observe ground truthing (2009-2010)
- 2009 NPS class
  - First public demonstration of ArchaeoMapper
  - Agency guests (Army IMA, LA SHPO, tribes)
- 2009/2010 small scale ground truthing
  - Verify interpretations using *ArchaeoMapper*
- 2010 brief agencies
  - SHPO, THPO, ACRA, others
- Concise overview
  - Ca. 5 pages, links to details on web
  - To very wide range of CRM professional
- Conferences, Technical Reports, Articles

Why the NPS class?

- Single best venue to reach current and future geophysical practitioners and sponsors
- 19th year*
- More than 650 past attendees*
- Tribes, fed and state agencies, SHPO, CRM firms, academics, students

From Dalan and De Vore (n.d.)

Why Los Adaes?

- Favorable for geophysical survey
- Rich archival history
- Diverse archaeological features
- Compelling geophysical image
- Potential to interest many CRM professionals

texasbeyondhistory.net

APPENDIX M: INDIVIDUALS INVITED TO ATTEND THE 2009 FIELD DEMONSTRATION

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